TEACHING PHYSICAL SCIENCES IN SECONDARY SCHOOLS

S K GUPTA

Written by an experienced teacher specialising in science education, this book is an endeavour to meet the requirements of B.Ed. and M.Ed. courses of Indian universities, keeping in view modern trends and practices useful for making physical sciences interesting and understandable to secondary school students.

The book is divided in two parts. The first part deals with the nature of physical sciences, methodology of teaching, instructional programmes, and evaluation; the second part is devoted exclusively to the "Content-Enrichment Programme" (physics and chemistry) which has been developed on modern lines as part of the syllabus of "Teaching of Physical Sciences" in many Indian universities.

Profusely illustrated and containing an exhaustive section on objective-type questions, the book should prove very useful to B. Ed. and M.Ed., M.A. (Edu.) students and science teachers in secondary schools, especially because there is a dearth of material in the specific subject area of teaching physical sciences

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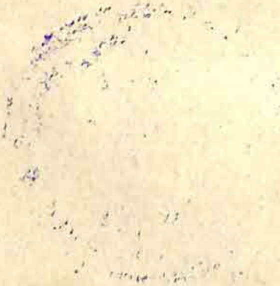
Teaching Physical Sciences
in
Secondary Schools



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To my sister
SUMAN
who left for heavenly abode in the prime of her life

Teaching Physical Sciences in Secondary Schools

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PREFACE TO THE SECOND EDITION

The second edition of the book is in a revised form with the latest findings and research in the field of science education. A few chapters with latest trends and practices in teaching of physical sciences have been incorporated to make it an up-to-date text-book.

The author is highly thankful to all the professors and eminent educationists who have appreciated the text book and encouraged me to write further. The book has been revised keeping in view their valuable suggestions.

The incorporated material will certainly add to the worth of the book. The book now covers the entire revised syllabi of B.Ed., M.Ed., M.A. (Education), M.Sc. (Education) and M.Phil classes of all the Indian universities and some of the foreign universities.

The following topics have been added to the revised book.

1. Innovations in Physical sciences.
2. Development of Science curriculum practical.
3. Practical concepts in Physical sciences with examples.
4. Behavioural objectives in Physical sciences.
5. Test constructions in Physical sciences.

I hope the revised edition of the book will certainly prove useful and appreciated by all the students, teacher-educators, and university teachers in the field of science education.

It is requested to all the teachers and students in the field to give their constructive suggestions for the further progress of the book.

Sharwan Kumar Gupta

PREFACE

Science plays a vital and pivotal role in the development of many qualities of head and heart in the individual thereby helping him to be a good citizen in the society—a crucial need of the hour. It helps him to be a useful productive and progressive member of the society. It makes him intellectually enlightened, vocationally fit and morally sound.

Science develops in students the qualities like truthfulness, honesty, open-mindedness and goodness. It makes him free from false-beliefs and superstitions. Because of the above-mentioned values of science, it finds a very important place in today's high school curriculum. Every body is expected to study science upto high school level.

The development of these qualities of head and heart depend not only on the study of the sciences by the students but also *the way* of teaching the science subjects to them. I would say, the approach and style of presenting the science instructions to the students is much more responsible for the development of these qualities. Students should be given opportunities to participate in the teaching-learning process. They should arrange their experimental work themselves, make their own investigations and express themselves by participating in different scientific activities and through various other science programmes like science fairs, science clubs and scientific excursions.

In this book, it has been elaborated how the scientific situations and opportunities could be created for the students. It has also been illustrated how the students can participate in these scientific activities and programmes in order to develop the above stated qualities. Various methods and approaches have also been discussed for teaching science through which the teacher can help the students to develop these qualities and make them socially efficient and socially acceptable citizens.

Teaching of Physical Sciences has been introduced as a compulsory subject at the high school level in the present system of education. Before the 10+2 System of Education, science was taught with an integrated approach under the head "Teaching of General Science." Nowadays the teaching of general science has been bifurcated into

and taught under the two main heads—(a) Teaching of Physical Sciences, (b) Teaching of Life Sciences. The methodology of teaching physical sciences is different to that of life sciences.

The books on teaching general science are readily available in the market, but there is hardly any text-book on Teaching Physical Sciences covering the latest syllabi. Hence this work "Teaching Physical Sciences in Secondary Schools" is an humble attempt by the author to fill this gap. The latest trends, approaches, technology and practices have been incorporated in the book which will certainly help teachers to make the teaching of physical sciences clear and understandable to their students. The book will be an asset to B.Ed. (Science), M.Sc. (Edu.), M.A. (Edu.) and M.Ed. students of the Indian universities.

The term physical sciences in this book has been restricted to the study of 'Physics' and 'Chemistry' only because at the high school level Physical Sciences are taught under these two heads, 'Physics' and 'Chemistry'.

The book has been mainly divided into two parts (a) Methodology and Technology of Teaching Physical Sciences, and (b) Content-Enrichment Programmes in Physics and Chemistry.

The Content-Enrichment Programme is a part of the present B.Ed. syllabi and finds its importance in the fact that in most of the schools, there is a single science teacher to teach science subjects. A Biology teacher, for example, is expected to teach Physics and Chemistry also. In order to enrich and refresh the biology teacher in Physics and Chemistry, universities introduced the content-enrichment programme, in the syllabi of B.Ed. students. The topics have been illustrated and disscussed with respect to the needs of our student-teachers.

Besides its usefulness to B.Ed., M.Ed., M.A., M.Sc. (Edu.) students of Indian and foreign universities, this book will also be helpful to 'in-service training courses' of the science teachers arranged by the Government from time to time to refresh their knowledge in methodology and audio-visual aids of science education.

Though every effort has been made by the author to discuss all the pros and cons of the subject, yet omissions may be expected. Distinguished teachers and scholars on the subject are welcomed to suggest their concrete and valuable opinions for incorporating the same in the next edition of the book.

Sharwan Kumar Gupta

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Part I

METHODOLOGY AND TECHNOLOGY OF TEACHING PHYSICAL SCIENCES

1

DEFINING PHYSICAL SCIENCES

Physics

Physics has been defined as the study of the properties of matter and energy.[1]

It concerns both the macroscopic and the microscopic state of matter. The peculiarity of this subject is that it perceives both with the same set of laws and generalisations. The Law of Conservation of Mass and Energy holds good both in the cosmic scale as well as the sub-atomic scale.

However, we should not look at Physics merely as a body of facts, or some important physical laws and generalisations which are to be investigated and applied to new situations. In fact, our notion of the subject should reflect its own true spirit. Many laws are merely crude generalisations or deductions. For Boyle's law, for example, we know that only perfect gases obey this law, although we are fully aware of the fact that no gas is perfect.

Then what is this law about? We know that most of the ordinary gases do not obey this law perfectly still we apply it in our daily life. The reason for this is that for all practical purposes, the deviation for the law under ordinary laboratory conditions is very marginal and beyond the capacity of scientific instruments to detect. So we satisfy ourselves with the important, although imperfect generalisation. Such instances could be quoted in almost all branches of Physics. The important thing is not the law itself but its valuable applications to new situations related to daily life problems and relationship with other set of laws and facts.

Chemistry

Chemistry has been defined as the study of the composition of substances and of their effects upon one another[2]. Chemistry has three main branches which are given below:

1. E.B. Vyarov, D.R. Chapman and Plan Isaacs, *A Dictionary of Science*, ELBS (ed), 1964.
2. *Dictionary of Science*, p. 73.

1. *Organic Chemistry.* The chemistry of organic compounds; the chemistry of carbon compounds excluding the metal carbonates and the oxides and sulphides of carbon. Originally, the chemistry of substances produced by living organisms, as distinct from the inorganic chemistry of substances of mineral origin.

2. *Inorganic Chemistry.* The study of the elements and their compounds. Inorganic chemistry usually includes the study of elemental carbon, its oxides, metal carbonates, and sulphides, while all other carbon compounds belong to the study of organic chemistry.

3. *Physical Chemistry.* The study of the physical changes associated with chemical reactions and the dependence of physical properties on chemical composition.

Relationship of Physics with other Subjects

Physics has got intrinsic relationship with philosophy. Earlier it was called 'Natural Philosophy.' Great philosophers like Galileo, Newton and others were great physicists in their time. They enlightened the horizons of scientific knowledge by their speculative and imaginative thinking. It is a strange fact that an important law in Physics, Planck's Law of Radiation,[3] came out as a conjecture and by empirical relationships. The speculation and imagination has an important place even in the realm of science and in expanding the frontiers of scientific knowledge.

The subject Physics is also intermixed with Mathematics. At the higher stage of learning, Physics is almost indistinguishable from Mathematics. Mathematics is the backbone of all Sciences. It is more true for Physics as it brings out its quantitative nature.

Biology in itself has been becoming more and more mathematical. Consider, for example, the science of genetics with its applications to plant breeding and animal husbandry.

The relationship of Physics with other science subjects like Biology, Agriculture, Chemistry and its importance can be seen through the uses of radio-active tracers and radio-isotopes, mentioned below.

Uses of Radio-active Tracers—Radio-isotopes[4]

Radioactive-isotopes, known as radio-isotopes, are produced by placing non-radio-active elements in a nuclear reactor and bombarding with neutrons till the elements become radio-active.

Isotopes of the same element behave alike. If they are injected into the body of an organism, they will join and move about with the

3. The energy of electromagnetic radiation (including light) is compared with discrete quanta, the magnitude of which is given by the product of Planck's constant and the frequency of the radiation.
4. Radio-active atoms of the same element (i.e., having the same atomic number) which differ in mass number are called isotopes of that element. The isotopes of an element are identical in chemical properties in all physical properties except those determined by the mass of the atom.

elements which are chemically alike. When isotopes are converted into radio-isotopes, their value as tracers in plant and animal research become enormous. Radio-isotopes not only behave like the body element to be studied—they also give off *glpha*, *beta* and *gamma* rays, which can be detected by a Geiger Counter[5] outside the body. Radio-isotopes can be used to study and explain life—processes, diseases, and chemical reactions in plants and animals.

Fortunately these radio-active tracers can be greatly diluted to reduce the amount of radiation in injections or exposures. Very small quantities of them, mixed with non-radiant liquid or solids, still send out rays that are strong enough to be easily detected.

Radio-isotopes in Agriculture

Radio-isotopes are being used to know more about fertilisers. By mixing tracer with ordinary fertilisers, scientists have been able to learn a great deal about how and when fertilisers should be applied to soil to get best results.

Plants make the best use of fertilisers only at certain times during their growth. For example, the element phosphorus (P) is needed by all plants. When radio-active phosphorus is mixed with normal phosphate fertilisers, the periods of greatest intake of fertilisers can be determined. By this method it has been found that there is great variation among plants. Potatoes, for example, depend upon fertilisers throughout their entire growth for the phosphorus requirement. Corn, on the other hand, when very young, depends a great deal upon fertilisers, but as the plants grow older, they depend more and more on the phosphorus already in the soil.

Radiation in Plant Breeding

Radiations cause mutations[6] in plants. Because of this fact radiation promises to be an important tool in plant breeding. Recent researches have shown that induced radiation produces many types of mutations in plants. The important thing is that the plant breeder may find a new superior type.

Radio-isotopes in Diagnosis and Treatment of Diseases

Some of the radio-isotopes commonly used in medical diagnosis are radio-iodine, radio-rodium and radio-phosphorus. Small quantities of radio-active atoms which are isotopic or chemically identical to the body element under study are injected into the patient. Then the building up of radio-activity in the area under suspicion is closely watched. An over-concentration of radio- iodine in the thyroid gland indicates that the gland may be producing too much hormones and other forms of radio-iodine are used to locate tumors in the human

5. *Geiger-Muller Counter*. An Instrument for the detection of ionizing radiations (chiefly *alpha*, *beta*, and *gamma*-rays, capable of registering individual particles or photons.
6. *Mutation*. Sudden change in Chromosomal DNA.

body. Faults in the circulation of blood can be detected with injections of radio sodium in a salt solution. As the tagged atoms in the salt travel through the blood vessels, a Geiger Counter held near the patients body will receive the radiations and indicate the pattern of circulation. Radio-phosphorus accumulates in the bones after being injected. Its density and location are clues to the progress of bone formation. The deformed and diseased bones can be healed.

Many forms of cancer can be treated with radio-active substances. Frequently radiations from lamps containing radio-active cobalt (Co^{60}) are used for treating cancer. For many patients these radiations are better than X-rays because the machine can be more easily adjusted so that the healthy tissues do not receive an overdose. Sometimes radio-active Cesium (Cs^{137}) is used.

Teaching of Physical Sciences with Other Subjects

Can simple equations in mathematics lesson be illustrated by experimental data obtained in a science lesson on specific heat,[7] latent heat,[8] or the simple properties of lenses, for instance? Can mathematics data with inverse ratio just before the science teacher diseusses Boyle's law? Can the two teachers decide upon the most interesting way of dealing with graphs, which often provide an excellent means of representing scientific facts? For example, the distances travelled by a stone falling under gravity, and the route taken through the air by a cricket ball may be connected with the graph of a simple quadratic. The measurement of angles and the drawing of triangles in geometry can be coupled with the study of the mariner's compass and the use of the prismatic compass in science.

When the geography teacher wishes to deal with climate, he should take it after the science teacher has given his lessons on air pressure, atmospheric humidity and their measurement, and on the heat and the construction and use of thermometers. Topics such as the relationship between plant and animal distribution and the density and activities of the human population, and the occurrence and composition of chalk hills and coral reefs, concern both geographer and scientist. Can geography lessons be fitted in after these in science which deal with the lower forms of life and the composition of chalk? Even if collaboration with other teachers may prove impossible in detail, the physical sciences teacher, giving his lesson on the preparation of carbon-dioxide, must draw attention to the fact that chalk is of equal and common interest in chemistry, biology, geology and geography. Coral sea-shells, limestone and other forms of chalk are all used as sources of lime. Coral and chalk have been formed from living

7. *Specific Heat*. The quantity of heat required to raise the temperature of unit mass of a substance by one degree.
8. *Latent Heat*. The quantity of heat absorbed or released in an isothermal transformation of phase. The specific latent heat of fusion is the heat required to convert unit mass of a solid to a liquid at the same temperature.

creatures, and the process continues today. Countless millions of the skeletons of these creatures have been gradually compressed, thus forming great reefs, mountain ranges and vast geological measures. The action of acids, or heat can release the carbon-dioxide taken in by the creatures millions of years ago. In mentioning such points the teacher not only forges links between the various branches of science but provides material which may fire the imagination of his pupils.

INCLUSION OF PHYSICAL SCIENCES IN THE SCHOOL CURRICULUM

The importance of science all over the world is now well-recognised, and it is generally accepted that some knowledge of Physical Sciences is an important part of a liberal education. We are living in what is called 'the scientific age.' Any education intended to fit us for graceful and purposeful living will be grievously ill-directed if it takes no account of the intellectual climate of the present day, permeated as it is with the ideas and hopes of the scientists.

The Benefits Derived from the Study of Physical Sciences

1. Physical Sciences give an essential background of knowledge for cultural development. It expounds the pupil's knowledge of the universe and his position in it; it helps in the appreciation and enjoyment of nature and life, it offers a basis for a proper and valuable use of increased leisure, and it stresses the need to take an active and intelligent share in the development of the community.

2. Physical Sciences give many opportunities to foster the scientific method and discipline, since it trains the pupils to observe and think clearly, critically and carefully. This training should, whenever possible, be applied to real and worthwhile problems affecting the personal life and thinking of the pupil, so that such benefits may be transferred to his other activities.

3. Physical Sciences stress the need to appreciate the meaning of scientific life, spirit and endeavour—open-mindedness, intellectual honesty, self-sacrifice and devotion—which may serve as ideals to the future citizen. Contributions made to community through the efforts and achievements of scientists should be known to all citizens since they are a distinctive feature of modern civilised existence.

4. Physical Sciences introduce the pupil to a knowledge of scientific facts needed not only for many trades and professions but also to enable the citizens lead happy, well-balanced and useful life. Future citizens ought also to know the possible influence of new scientific discoveries and should realise the need for proper control. It is, therefore, necessary to understand, as a minimum, the simpler words and definitions in Physical Sciences, the relationship between Physical Sciences

and other fields of knowledge, and the elementary facts and principles of this subject, so that in later life the pupil may keep himself informed of important developments.

In order to satisfy the major needs of a student, the requirements of Physical Sciences have been classified with respect to three standpoints:

1. As a citizen, with certain civic and social duties and responsibilities.
2. As a worker, is duty bound to bear his share of the economic load.
3. As an individual, who must have varied non-vocational interests and permits if he wishes to lead a normal and well-balanced life.

Under these three headings, the effective teaching of Physical Sciences may help improve the student's health, his wise use of leisure, his ethical standards, his manipulative skills as citizen.

A physicist or a chemist obtains first hand information to a great extent, from direct contact with materials, and is able to build up the subject-matter from facts which he obtains personally and can verify for himself. He repeats an experiment—a test carried out under certain known conditions—time after time in his search for a satisfactory explanation and he varies the experimental conditions to find the underlying relationship. He pays special attention to the degree of accuracy and the methods of obtaining results. Indeed many of his discoveries are due to long and patient measurement with accurate instruments. He discovers and formulates laws, and verifies his assumptions by studying a small number of isolated substances under precise conditions in his laboratory. In doing so he must devise experiments to test his hypothesis and to deduce general principles.

Training of Scientific Method

The first steps in the scientific method of approaching a problem are inductive, since the pupil (a) perceives the problem, (b) collects and organises relevant information, and (c) forms a tentative hypothesis which he tests. He then makes, and in turn tests, other hypothesis using additional information, and then he selects the hypothesis which best fits the evidence available. Finally and deductively, he applies the generalisations obtained from the hypothesis to specific cases. A hypothesis is thus a reasoned guess or deduction and is used to predict further results. If it correctly forecasts results which may be confirmed experimentally, it is called a *theory*. A theory, however, still contains an element of doubt, but with modifications it may be the means of formulating a new law. A law is a well-confirmed statement of relationships based on experimental proof.

Development of Scientific Outlook

The teacher should bear in mind the paramount need to encourage

the student to think critically to make unbiased conclusions as a result of logical thinking and to be precise and honest in his observations and recordings. The scientific outlook of impartiality, critical assessment of accepted opinions and the classification of all occurrences on the same emotional level, should influence our conduct, norms, and our outlook to the government of our own country, in the same way that it has affected our work, wars and hygienic conditions.

Transfer of Scientific Attitudes and Values

The relationship between scientific method and mental discipline introduces ideas on formal training. Habits of scientific thought and method are much better acquired by the study and practice of science itself. There is no automatic transfer to any other subject or sphere of life. It is likely, however, that specific abilities and character traits (notably persistence, industry and honesty) may be transferred. It should be clearly understood that physical sciences, as the important branches of science, is a method and a habit of thought, and that subject-matter training in skill, and teaching technique should be selected accordingly. It should be well and closely linked with the pupil's emotions and common interests. Further, the pupil must deliberately be encouraged to use the scientific approach in solving everyday problems. Transfer of training is most likely to take place if this is consciously done and if similar facts, principles and ideals are considered together. The 'problem' or 'modified heuristic' approach appears to be particularly valuable when used together with realistic probl ms of everyday life.

The teacher's enthusiasm, his attitude to the subject, his effective demonstration methods and his learning should inspire the pupils with a thirst for knowledge in physical sciences. And the greatest asset that the teacher can possess is enthusiasm.

The boy who takes with him from school an ideal of truth and of knowledge for its own sake and of the discipline which science induces, can play an important part in his world of the future.

Thus physical sciences are both a product and a process. A study of it helps both the society and the individual. It is important for the society for developing scientific outlook among the members for economic and agricultural progress, for modernisation and for inculcating certain qualities of head and heart essential for democracy. Study of physical sciences have informative and disciplinary values as far as the individuals is concerned. It provides him with sufficient knowledge for a successful living and also develops in him scientific outlook and attitude.

2

AIMS OF TEACHING PHYSICAL SCIENCES

The reasons for universalisation of teaching of Physical Sciences at school level fall under two main categories: usefulness to the country, and usefulness to the pupil.[1]

Modern states especially a democratic country requires men with scientific thinking and training such as engineers, chemists and doctors. These men must start their science sooner or later, and the sooner the better. If the schools do not provide science as a subject, then many pupils may never have a chance of finding out even if they have the aptitude and interest for the subject.

The governments of modern states make use of scientific knowledge immensely for their proper functioning. In nearly every country the departments of agriculture, education, health, police, posts and telegraphs, railways, and surveys, employ scientists. These departments send out orders, many of which will be the result of scientific work and these orders have to be carried out by officials, merchants and farmers. If they are not understood the orders will be carried out badly or not at all; so some knowledge of science is a must to everybody.

We now come to reasons for learning science which concerns the body. The first is that a few boys will use science to earn their living. They are the boys with better aptitude for science who become engineers, doctors, and agricultural officers.

The second reason is that boys will live in a world where science is important. Their governments will send out orders which will be easily understood by those who have a background of scientific knowledge. In other words, science will help a boy in his day-to-day life.

The third reason is that many boys enjoy learning science, because it deals with things of their environment and answers questions they wonder about. They are ready to accept the subject, so they learn it well.

A man who does not know about the discoveries of physics, chemistry and biology in the last three hundred years cannot be called

1. Owen, C.B., *Methods for Science Masters*, ELBS, 1966.

properly educated. The discoveries of Newton, Lavoisier, Pasteur and Darwin, produced order and system, where there was confusion before. Boys at the High School stage have a strong desire for knowledge of system. While the facts of science are important, it is also important that boys should understand the system of observation, guess and experiment which we call the scientific method.

The most important of the reasons for learning science is that it has a value as character training. "It develops an attitude that is a habit of thinking, feeling and acting, which is a mixture of curiosity and caution: curiosity leading to correct observations, and caution in arguing from the observations."[2]

Our aims, then, are to help boys to live in the modern world, to introduce them to the methods and systems of science, and to develop some attitudes we think valuable.

A. Objectives of Teaching Physical Sciences

What are objectives? By education, we mean to bring about desirable changes in the behaviour of the pupil. We expect these changes in a particular direction so as to satisfy the needs of the individual and the society. These needs of the individual and society will determine the expected terminal behaviour of the pupil after giving him a particular amount of education. The terminal behaviour is not observed only in terms of the knowledge of facts, but developing new attitudes, new skills and new ways of thinking. "A Science programme must be judged by its effect on individual pupils, not by the number of textbooks read or the percentage of syllabi covered. Science can justify its place in the curriculum only when it produces important changes in young people—changes in their ways of thinking, in their habits of action and in the values they assign to what they have and what they do."[3]

The objective of good science teaching as defined by Sir J.J. Thomson[4] in his report on the position of natural science in the educational system of Great Britain is two-fold:

1. It should train the mind of the student to reason about things observed, and develop his powers of weighing and interpreting evidence.
2. It should also make him acquainted with the broad outlines of great scientific principles with the ways. These are exemplified in familiar phenomena and with their application to new situations for the service of man.

The objectives of Physical Sciences depend upon the following

2. op. cit., p. 8.
3. Walter, A. Thuber and Alfred, T. Coflette, *Teaching of Science in Today's Secondary Schools*, Ch. II, Prentice Hall, 1964.
4. Natural Science in Education (H.M.S.O.), p. 58.

factors: Need of the individual, need of the society, and applications of science to face new challenges in life. Based on these factors, the important objectives are discussed below:

Knowledge

The basic knowledge of the fundamental laws of Physics and Chemistry are essential to make meaningful everyday experiences, and understand the environment surrounding a man. It also helps in relishing the applications of scientific knowledge to new situations for the solution of problems in day to-day life.

(*a*) The pupils acquire the scientific knowledge helping them better understand the environment through numerous phenomena like: the formation of dew on green grass and leaves in winter nights, twinkling of stars in the star-studded sky, thunder and lightning in rainy season as a result of electric discharge from two opposite charged clouds, a dust storm in summer, the blue colour of the sky and deep water, and the formation of rainbow after the rain on the basis of the laws of refraction of light.

(*b*) The knowledge of Physical Sciences helps in making the pupil understand the application of science in everyday life. For example, to every action there is an equal and opposite reaction. It is an important law in Physics which can be assimilated in the life of the pupils in the form that good actions follow good results. Newton's Ist Law of motion helps them to safeguard against accidents and unforeseen calamities. When one gets down from a moving train, then he naturally moves forward for a while in the direction of the moving train. Similarly, if you want to get into a moving train or a bus run for a while in the direction of the train or bus to get momentum and then catch it. Don't be in a moving train or bus without support otherwise you are likely to fall when the train or bus suddenly stops.

The knowledge of Chemistry can be applied for leading a better life. The importance and use of going for a walk in the morning, taking balanced diet, use of disinfectants and antiseptics, purification of water and cleansing action of soap can well be reflected by chemistry.

(*c*) The knowledge of Physical Sciences helps to remove superstitions and false beliefs from the minds of the pupils. For example, the observation of fire on marshy land was considered due to the presence of some evil spirits. But it has been reasoned that fire is produced as a result of the spontaneous burning of hydrides of phosphorus and methane, produced due to the decomposition of animal and vegetable matter.

(*d*) Knowledge of Physical Sciences helps the students to follow and interpret intelligently the scientific news and literature which they come across in their day-to-day living. The latest scientific

information helps them a lot to face new challenges intelligently and boldly.

Training in Scientific Method

Students of Physical Sciences get training in the use of scientific method by performing experiments themselves in laboratory; and by observing experimental demonstrations arranged by the teacher for them. The scientific method involves:

1. The appreciation of the existence of a problem and a desire to solve it.
2. The accumulation of facts and data which are pertinent to the problem.
3. The formation of hypotheses as partial explanations, their testing and their acceptance or rejection.
4. Logical interpretation of data with an unwillingness to accept unless supported by adequate valid evidence.

The use of these steps means that the individual first recognises the existence of a problem to be solved and sets about to solve it. He next establishes all available facts concerning the problem, which involves the accumulation of data. On the basis of these facts he constructs hypotheses which are logical explanations of the parts of the original problem. These hypotheses he must clearly recognise as tentative and must not confuse them with proved conclusions. He then tests his hypotheses by experimentation and further accumulation of evidence to establish their degree of adequacy. If a given hypotheses is supported by sufficient evidence, it may be accepted as a conclusion and as a step in the solution of the problem.

To be of true worth educationally the frequent use of the scientific method must produce in the minds of the student an attitude towards all problems of life which demands that claims be proved, that facts take precedence over prejudices and desires. In short, the fruits of scientific method are scientific thinking and attitudes in the processes of daily life.

Development of Scientific Attitudes

As the ability to think and, in so doing, to use the scientific method depends upon a knowledge of facts with which the thinking is done and as the drawing of inferences, the making of generalisations, and the application of principles depend largely upon the ability to think logically and scientifically, so the formation of scientific attitudes is the correlation of all these.

Miller and Blaydes[5] state "an attitude is a condition of mind involving imagination and emotional states which are the result of previous experiences. Attitudes condition behaviour, establishing patterns of conduct. Attitudes are ethics."

5. Miller, David F. and Blaydes, Glun W., *Methods and Materials for Teaching Sciences* (2nd Ed.), Tata McGraw-Hill Publishing Co. Ltd., Bombay.

The Physical Sciences inculcate among the individuals, the attitudes of a scientist like critical observation, open-mindedness, suspended judgement, freedom from superstition and false beliefs, truthfulness and respect for other's points of view. Such attitudes are of paramount importance for "social efficiency" which we want in a democratic society. One must not fail to recognise that a society is but a group of individuals each of which contributes in some measure, however small, to the characteristics of that society.

Development of Abilities and Skills

Intellectual abilities and skills have been described as the development in pupils of a facility for problem-solving, for critical thinking, and for reflective thinking. Whatever label is actually applied to this purpose of science teaching, possession of it becomes apparent if pupils can take action to find appropriate formation and techniques from their previous experience and bring them to bear on new problems and situations. That pupils are able to take action in new situations means that they are able to some degree to analyse and understand the new situation, that they have knowledge of those methods which can be readily utilized, and are able to discern the relations between their previous experience and the new situation. Possession of the necessary manipulative skills is clearly of considerable value in the solution of practical problems.

To Provide Work for Leisure

With the development of the manipulative skills the pupils learn to improvise scientific apparatus and experiments and pick up different scientific activities from different scientific hobbies and science club programmes. This helps them to make use of their leisure time by making things of common use, i.e., ink, soap, candle, phenyle, cosmetics, bootpolish, chalk-sticks, etc., and initiate creative and exploratory projects. These activities provide to children the opportunities for profitable use of leisure time.

Training for Better Living

The students of science should know the laws of health and hygiene and should be given training in healthful living. From the knowledge of physics and chemistry, they can know the usefulness of ventilation, morning walks, Sun-rays and vitamins, etc. They should be taught to take care of the body and to improve their surroundings, thereby improving the standard of living. They should know the ways and means of prevention and eradication of diseases and should be able to adjust themselves with their own domestic, social and physical environment and the economic, social and cultural conditions of the country.

Providing Basis for Vocational Career

Science forms the basis for many courses and career of purely vocational nature thus preparing the children for many professions, e.g.,

Engineering, Medicine, Agriculture, Architecture, Aeronautics, Dairy and Textiles.

In addition to being an integral part of general education, the science teaching at the secondary stage should prepare the students for some vocation and specialisation in the individual subjects. A different type of knowledge, skills and training should be given to pupils in accordance with their choice to go to higher studies or some other profession mentioned above.

Scientific Appreciation

Scientists of all races and of all lands have disclosed to all of us, the mysteries of nature. "Our efforts should not therefore be confined to the teaching of understandings alone because the elements of admiration, emotions and intellectual pleasures cannot be altogether easily discarded."[6] Again: "Adjustment to the situations encountered in modern living are not made on the basis of cold factual applications alone, but also with feeling and emotion. Each adjustment situation is a complex of feelings, attitudes and understandings. It would seem then that a background of appreciations which are peculiar to science should become one of the desired outcomes of instruction in this area."[7] The content in science if developed in evolutionary manner would reveal the fascinating historical and biographical incidents of great scientists, stories of scientific romance, and adventures, etc., which provide for emotional satisfaction and develop emotional depth. Appreciation cannot be taught as such. It develops from understandings and attitudes. History of science, biographies of scientists and impact of modern science on human lives provide ample scope for appreciations. The capacity for appreciation enables the pupils to realise the significance of various discoveries and their impact on human life and society, to value the sacrifices and painstaking efforts made and hardships undergone by scientists in the course of their discoveries, to get excitement and thrill at every scientific achievement, to show eagerness to convey their job and thrill to others, to shows respect and admiration for great scientists and to realise the importance of science in human progress.

B. Behavioural Objectives in Physical Sciences:
Objectives and the Daily Lesson

The science teacher who wishes his pupils to develop scientific attitudes of truth, honesty, questioning thoughtfully, examining critically, open-mindedness, and suspended judgement, and who plans his daily lessons accordingly, cannot himself be rigid in his interaction with individual pupils in the class. To state in the lesson plan that

6. Narendra Vaidya, *Problem Solving in Science*, S. Chand & Co., p. 47.
7. Heiss, Obourn and Hoffmann, *Modern Science Teaching*, McMillan Co., ch. 2, 1961, p. 34.

scientific attitudes constitute one of the aims of the lesson would be meaningless if the science teacher presents science as dogma—a subject of finality rather than one of "Let's discover and continue to question."

In the daily lesson plan, the teacher will determine whether the objectives will be limited to the development of scientific information alone. The teaching of science for critical thinking should be carefully planned along with the content. Burnett[8] states the following teaching objectives that are required for the development of critical thinking: To work with our students in such a way that they increasingly[9],

1. Discover problem situations.
2. Delimit problems into workable proportions.
3. Think critical hypotheses.
4. Collect relevant reference data.
5. Gather experimental or observational data.
6. Work cooperatively.
7. Recognize personal bias and opinions of others and consider them in making judgements.
8. Communicate effectively and with accuracy.
9. Consider the limitations of both data and conclusions.
10. Recognize the applicability of scientific methods to non-science problems.
11. Recognize the universality of cause-and-effect relations within the framework of probability (the uncertainty principle).

It is neither possible to attain these objectives in the daily lesson; nor at the end of a given physical science course. But at the end of the course, the science teacher can expect that a progress is towards the development of these objectives. Therefore, the science master may select some of the above-mentioned objectives in planning a daily lesson.

Criteria for Selecting Objectives

There is a general practice to give less attention to the objectives of a science lesson than to the content, aids used or methods of teaching. A science teacher should at least know why he is teaching a particular lesson. If he does not know, the lesson takes the form of either a general lecture which only emphasizes the retention of a specific principle or law which is likely to be forgotten by the learner. A basic criterion in formulating objectives is whether a science teacher can evaluate the degree to which an objective is developed. The evaluation

8. Burnett, Will R., *Teaching Science in the Secondary School*, New York, Rinehart and Company, 1957, pp. 176-77.
9. Washton, Nathan, S., *Teaching Science Creatively in Secondary Schools*, W.B. Saunders Co., Philadelphia and London.

may be in the form of pencil-paper test, observation of pupil behaviour by the teacher, anecdotal record or any other device fit for measuring or evaluating the degree of growth in the development of an objective.

The National Society for the Study of Education in America[10] employed the following criteria in formulating objectives of science teaching:

1. Is the statement practicable for the classrom teacher? Is it usable? Does it develop logically from a simple step to the next step and so on? Does progress toward the development of the objective actually occur?

2. Is the statement of the objective psychologically sound? Is it based on accepted principles of learning?

3. Are the objectives possible of attainment under reasonable conditions? Are they suitable to the various levels of development in a class of heterogeneous learners?

4. Are the stated objectives universal for all groups in a democratic society?

5. Are objectives avoided that are limited by geographical, religious, racial, and political considerations?

Classifying Objectives in Science Teaching

Unless the Science Teacher studies the various categories of science objectives before planning instruction, the tendency is to teach only for the understanding of the scientific idea or concept. Since the newer science programmes have been emphasizing other objectives such as problem solving, science inquiry, open-mindednes, open-ended experiments for critical thinking and scientific attitudes, the skills in laboratory for inductive and deductive reasoning, stimulating interests and appreciations of science via scientific projects, research and challenging demonstrations, it will be helpful to categorize science objectives.

This may reinforce the objectives of teaching other than the mere learning of content which frequently is given for purposes of memorization.

Some courses of study list general and specific objectives. Others state them in terms of content, teacher aims, pupil attitudes, behaviours, or needs. For a more thorough preparation of daily lessons, unit plans, and syllabi, the following categories may serve as a guide to the teacher.

A. *Functional information* or facts about such matters as:

1. Our Universe—earth, moon, sun, stars, sky, weather, seasons, etc.

10. National Society for the Study of Education: Science Education in American Schools, Forty, sixth Year Book, Part I, Chicago, University of Chicago Press.

2. The nature of matter—atoms, elements, compounds, etc.
3. Energy—sources, types.
4. Contributions of Science—radio, television, telegraphs, satellites.

B. *Functional concept*, such as:

1. Space is vast.
2. The earth is very old.
3. All matter is probably electrical in structure.

C. *Functional understanding of principles*, such as:

1. Changes in the seasons and differences in weather and climate depend largely upon the relation of the earth to the sun.
2. Energy can be changed from one form to another.
3. All matter is composed of single elements or combination of elements.

D. *Instrumental skills*, such as ability to:

1. Read science content with understanding and satisfaction.
2. Perform fundamental operations with reasonable accuracy.
3. Perform simple manipulatory activities with science equipment.
4. Read maps, graphs, charts,, and tables and to interpret them.
5. Make accurate measurements, readings, illustrations, etc.

E. *Problem-solving skills*, such as ability to:

1. Sense a problem.
2. Define the problem.
3. Study the situation for all facts and clues bearing upon the problem.
4. Make the best tentative exaplanations or hypothesis.
5. Select the most likely hypothesis.
6. Test the hypothesis by experiments.
7. Accept tentatively, or reject the hypothesis and test other hypothesis.
8. Draw conclusions.

F. *Attitudes*, such as:

1. Open-mindedness—willing to consider new facts.
2. Intellectual honesty—scientific integrity, unwillingness to compromise with truth as known.

3. Suspended judgement—scientific control, withholding conclusion until all available facts are known, not generalizing from insufficient data.

4. Appreciations, such as:
   (1) Appreciations of the contributions of scientists.
   (2) Appreciation of basic cause-and-effect relationships.
   (3) Sensitivity to possible uses and applications of science in personal relationships and disposition to use scientific knowledge and abilities in such relationships (scientific attitudes).

H. *Interests*, such as:

1. Interest in some phase of science as a recreational activity or hobby.
2. Interest in science as a field for a vocation.

Psychological researches suggest that students must be taught basic facts and how they can be related to the development and understanding of a major idea or scientific principle. It cannot be assumed that all students have the ability to synthesize the facts and put them together to 'spell out' a principle or a law. A few students may have this ability to transfer and connect the various parts to the whole idea. In general, the science teacher should provide laboratory situations, anecdotes, demonstrations, research and other learning activities that will help to develop the students ability to synthesize and to integrate specific facts into basic understandings. Some students may need to be shown how this can be done.

Statement of Science Objectives

Whether one teaches a science course in Physics or Chemistry at secondary school, it is helpful to state the objectives for a given course and to select the most appropriate materials and procedures for effective teaching to develop these objectives. The following objectives were adapted from those that appeared in the Forty-sixth Year Book of the National Society for the Study of Education.

1. Growth in functional understanding of scientific phenomena that are part of the child's environment.
2. Growth in development and understanding of scientific concepts and principles that function in children's experiences and help to explain them.
3. Growth in the use of manipulative, experimental, and problem-solving skills which are involved in investigations in the area of science.
4. Growth in the development of vocational and avocational interests in Science.

5. Growth in such desirable habits and attitudes as open-mindedness, intellectual honesty, suspended judgement, and respect for human dignity.
6. Growth in appreciation of the contributions and potentialities of science for the improvement of human welfare and in appreciation of dangers through its misuse.
7. Growth in those moral and spiritual values which exalt and rectify the life of the individual society.

The goals which appear in the Fifty-ninth Year Book of the National Society for the Study of Education in Part I, which, in addition, lists appreciations, attitudes, and specific abilities or skills such as:

1. Reading and interpreting science writings.
2. Vocating authoritative sources of science information.
3. Performing suitable experiments for testing ideas.
4. Using the tools and techniques of science.
5. Recognizing and evaluating assumptions underlying techniques and processes used in solving problems.
6. Recognizing the pertinency and adequacy of data.
7. Making valid inferences and predictions from data.
8. Expressing ideas quantitatively and qualitatively.
9. Using the knowledge of science for responsible social action.
10. Seeking new relationships and ideas from known facts and concepts.[11]

The following is the list of objections that can be used in teaching physical sciences:

1. To provide students with the necessary knowledge, skills and attitudes in order that they may:
2. Understand the world of physical nature, and be able to interpret natural phenomena.
3. Have some appreciation of the background of the civilization which is our heritage.
4. Understand the social, economic, and spiritual forces at work in society and develop a sense of social responsibility.
5. Gain a better understanding of the meaning and purpose of life and a truer sense of values.
6. Participate more effectively in solving problems of contemporary society.
7. Maintain and improve health and share in the responsibility for protecting the health of the community.

11. National Society for the Study of Education: Rethinking Science Education, 1960, p 37.

8. Attain an emotionally stable personality and make a worthy social adjustment.
9. Utilize a scientific approach in solving problems dealing with society and human welfare.
10. Be better fit for family and marital relationship.
11. Communicate effectively through oral and written expression.
12. Develop a code of behaviour based on ethical principles.
13. Recognize the interdependence of the different peoples of the world.
14. Recognize and accept one's personal responsibility for fostering international understanding and peace.
15. Appreciate the best in literature, art, and music, including drama, the dance, radio and motion pictures.
16. Discover their own abilities, aptitudes, and interests and choose a vocation.
17. Understand the place of the consumer in society and to learn to become an intelligent consumer of goods, services and time.

The above objectives are stated primarily in terms of behaviour changes that students are expected to undergo in a gradual manner as they acquire additional knowledge, skills, and attitudes.

3

METHODOLOGY FOR TEACHING PHYSICAL SCIENCES

Demonstration Approach for Teaching Physical Sciences

For quite some time it was considered possible to teach science by chalk and talk method, lecture method. Alongwith this some provision is made for practical work to be done by students in the laboratory. Generally it is found that there is no s.nchronisation of the experimental work which students are doing in the laboratory and the theory which is taught to them in the class. In this way the teaching of Physical Sciences tends to be boring because the charm of learning of physical sciences through experimental work is lost.

Another way to teach Physical Sciences is to let the students of science make as many experiments as possible, and let them do experimental work in small groups. However, sometimes, it is not possible to let the students make experiments themselves. Time may be too short or the material required may be too expensive. Under these circumstances classroom demonstrations may seem to be the appropriate sciution. Demonstrations are effective and motivational too. They are essentially helpful in creating interest of the pupils in the lesson.

Demonstration method consists of presenting and making clear the subject-matter to the students, by performing experiments before the students. The teacher performs the experiments with the active cooperation of the students.

In our country the problem of indifferent teachers is most acute. If all the teachers are trained in the art of demonstrations then we may have dull teachers but we will not have dull lessons.

Demonstrations—When?

The Demonstrations could be used:

1. to introduce a topic,
2. to pose a problem,
3. to make some quantitative measurement,
4. to perform experiments beyond the ability of the students,
5. to motivate students.

Demonstrations—How?

There are a few basic conditions which must be satisfied for a successful effort.

(1) *Special Demonstration Apparatus*: The first requirement of classroom demonstration apparatus is that it should be large enough to be seen clearly by all the pupils. For example, a meter should have lines of scale division of at least 3 mm thick, and the whole instrument must be of the corresponding size. Generally, 3 to 4 times the size of the ordinary classroom apparatus would be good enough for this purpose. Electrical meter should be large enough and dial size 6″ should be appropriate.

(2) *Large and Spacious Classrooms:* It is often found, that the space in the classroom is not quite enough. For a class of 30-40 students, a classroom of 60-70 square meters should be sufficient. Adequate provision of light, water and electricity is needed.

(3) *Demonstration Table:* The size of the demonstration table will depend upon the size of the classroom. For ordinary classroom (60-70 sq. meter), a table of 7.9 feet in length and 2½-3 feet in breadth should be sufficient. This table should contain all the necessary, electrical, water and gas supplies. It would be better if all the switches of light in the room are on or near the table, so as to enable the teacher to control the lights as he wishes. The advantage of this arrangement would be that the supplies would not obstruct the view of the class. Sometimes the shape of the table could be made either semi-circular or slightly curvilinear. The additional advantage would be that the teacher can reach all parts of the table with equal facility. There should be proper illumination on the table. Special electric lights or window arrangement should be made on the ceiling above the table so that the visibility of that area is increased.

(4) *Use of Demonstration Kits:* At the school level, several sample kits (Physics, Chemistry) prepared by N.C.E.R.T., New Delhi, are available which can be profitably used in the demonstrations. A good kit is capable of a large number of experiments. These kits are quite simple in design and highly instructive.

Useful Hints for Improving Demonstrations

The following are useful hints to improve demonstrations:

1. Draw a large-scale drawing of the apparatus employed in the demonstration work. Before starting the demonstration the function of each part is to be explained.

2. Try to involve as many students as possible in conducting the experiments. This way they would feel involved in the experiments.

3. Always remember that the demonstration is for the students and not for the teacher. The students in back row as well as in the front row should be able to see what is going on.
4. Be honest to accept the mistake if the demonstration fails for any reason. Or try to convert that failure as a problem to the students. This will inculcate the habit of honesty and integrity in the students which is one of the prime purposes of science teaching.
5. Try to involve the students into discussion, whenever the opportunity presents itself during the demonstration.
6. Do not be silent for long intervals, while conducting the experiments, or adjusting the apparatus. Silence on the part of the teacher distracts the attention of the students. If nothing is to be explained, tell them simply what you are doing.
7. Do not place all the pieces of the apparatus on the table in a confused way. The apparatus to be used and the apparatus which had been used, should be kept on the left hand side and right hand side of the table respectively. The demonstration table should present a well-ordered scene.
8. Try to use as simple an apparatus as possible.
9. Give a clear statement of what you are to do and what the students must look for before starting the actual practice.
10. Make a series of the demonstration beforehand, only then you will know whether or not all the parts of the apparatus are functioning properly. Should the apparatus need some adjustment or repair, this should be immediately run into.
11. Perform the demonstration at the appropriate time. If it is shown too early then the class would be unprepared to appreciate its importance. On the other hand if it is delayed too long this would diminish its effectiveness.
12. Make sure that the demonstration is not done too fast. Children at the secondary stage need time to grasp the full meaning out of it.
13. Choose an appropriate colour for the apparatus. A black disc, rolling on a black inclined plane, on a black coloured demonstration table against a black chalkboard shows nothing. Try to use bright and contrasting colours. You may even have to colour various parts of the same apparatus for better visibility.

Limitations of Demonstration Experiments

1. Only a few pupil can actively participate in any one demonstration. Thus a demonstration often becomes teacher activity rather than a student activity.
2. Without the use of large apparatus, demonstrations are often not visible to the whole class. Teachers tend to neglect the back-benches.

3. Students may miss the main purpose of the demonstration and the details of the apparatus used.
4. It is quite a frustrating exercise if the experiment fails for one reason or the other.

Relative Merits of the Demonstration and Individual Methods

Demonstration work, however, links up with individual work in many ways. Demonstrations point out the correct use of the apparatus. In individual experiments the pupils learn methods of manipulation, and the scope and limitations of the apparatus. In a demonstration, the teacher shows how to control the variable conditions, how to avoid accidents and breakages and in general, how to secure significant results. When experimenting, the pupil should be encouraged to initiate the teacher's method. At first he will be handicapped by lack of experience, and it is only by constant practice that he will gain the necessary skill. After his own failures, an intelligent pupil will realise his limitations, and in future observe the demonstration methods with more care.

The demonstration lesson is instructive for all pupils, it is particularly helpful to weaker pupils, who are thereby given opportunity for appreciating and learning the fundamental priciples of Physics and Chemistry. Less scope is however, offered in demonstrations for observing and recording unusual changes. In addition, physical tests especially that of smell and colour changes must be done individually. It is, for example, almost impossible to describe in words the difference in smell between chlorine and hydrogen chloride. These gases must be tested personally by the pupil and, therefore, as it is inadvisable to spare the time with a large class to call up individuals to the demonstration bench, the pupils themselves must do the experiment. Small quantities of the gas, usually a solution in water, may be put into a test tube and plugged lightly with cotton-wool. The test tube can then be passed round the class.

Individual approach is preferable in a demonstration, since the pupil may himself plan an investigation, carry out the necessary experiments to solve the problems, develop his manipulative skill and psychologically satisfy his own demands for activity and for getting first-hand personal information.

Problem-Solving Approach to Physical Sciences

This approach enjoys the highest prestige, as compared with other approaches of teaching science among science teachers all over the world. It is another thing that teachers find difficult to apply it in the classroom and laboratory for teaching their lessons.

Meaning: Problem-solving is a process of raising a problem in the minds of the students in such a way as to stimulate purposeful reflective thinking[1] for arriving at a rational solution. The elements

1. *Reflective thinking*: Training in scientific method—this will involve scientific attitudes of mind, habits and skills.

seem to be involved here: a situation, a goal or an end involving some aspect of the situation for which no ready-answer can be given and a desire or motive that stimulates an attempt to find the answer.

Problem-solving takes place when a problem-solver accepts to solve it as well as when his previous experiences or patterns of behaviour are insufficient to enable him to provide an acceptable solution. In such a case, solution becomes possible only when he acquires new knowledge upon relationships which have not been seen before.

Problem-solving method: Problem-solving takes place as soon as the problem is perceived by the problem-solver and is aimed at to reach the goal stated by the problem. The problem is supposed to be not only new but also at the same time, there is supposed to be no direct solution available to the problem-solver at the time of its presentation. Moreover, it is also assumed that the problem-solver possesses the basic information needed to solve the problem. A method, which employs this approach is called the problem-solving method or sometimes, the scientific-method for teaching of Physical Sciences.

Stages in problem-solving: In the classroom situation, problem-solving can be viewed in two phases, namely, a way of thinking and a way of teaching. If problem-solving is considered a joint or cooperative venture, it is then possible to identify the following stages:

(*a*) *Problem survey*—analysing a potential problem situation for items to be studied.

(*b*) *Problem description*—providing a clear statement of the problem to be studied.

(*c*) *Problem discussion*—making sure that the students understand what is involved in the problem.

(*d*) *Problem limitation*—isolating those parts of the problem that can be attached profitably.

(*e*) *Planning for action*—preparing suitable hypothesis for investigation.

(*f*) *Further analysis and limitation*—tentative testing of hypothesis to identify those most likely to yield a solution.

Steps involved in Problem-solving Method

1. Setting the problem;
2. Defining the problem;
3. Analysing the problem for solution;
4. Collecting the data for all possible clues;
5. Interpreting the data;
6. Formulation of tentative solution or hypothesis;
7. Selecting and testing the most likely hypothesis.

8. Drawing conclusions and making generalizations.
9. Application of generalizations to new situations.

1. *Setting the Problem:* The setting of the problems for study is very vital to the success of learning and should be carefully planned by the teacher. A cooperative approach may be used in which the teacher opens up the field for investigation and suggests places where problems may exist. Another method of setting the problem is to demonstrate some experiments in such a way so as to raise questions and problems. Some characteristics of a good problem are given below:

1. The problem should be suited to the maturity level of the students.
2. Problem should fit in the curriculum.
3. It should be interesting to most of the students.
4. Problem should be possible of solution with materials at hand.

2. *Defining the Problem:* The students now define the problem in a concise, definite and clear language. Students may write down the statement of the problem which may be read and discussed in the light of the characteristics of the problem given above.

3. *Analysing the Problem for Solution:* The analysis of a problem is an essential step towards securing information bearing on its solution. When the single major factor in a problem situation has been isolated, further analysis should reveal the key words or ideas for solution.

4. *Collecting the data from all Possible Clues:* The teacher suggests reading references about the problem. In collecting the evidence bearing on the solution of the problem, the pupils will be called upon to use as many devices such as textbooks, field-trips, experiments, models, graphs, moving pictures, etc. Each of these devices calls for a special set of skills for which pupils must have guidance and instructions.

5. *Interpreting the Data:* It is a very important and at the same time a difficult step as it involves reflective thinking. It should be clear at the outset that this aspect of problem-solving behaviour is not a specific but a complex of many skills and abilities. In approaching the question of how children may be taught to make reasonable interpretation of data, it is essential to break the large areas down into simpler abilities and then to consider ways and means of getting classroom situations for developing these. The students may be asked to arrange and organise the data and then be asked to analyse the evidence to find out if there are any similarities and differences in the results.

6. *Formulation of Tentative Hypothesis:* Following the analysis of the data the students list all the inferences which can be drawn. The hypothesis is an assumption or proposition whose tenability is to be tested on the basis of the compatibility of its implications with empirical evidence and with previous knowledge. A good hypothesis should explain existing data in simpler terms and should be stated as concisely as possible.

7. *Selecting and testing the Most Likely Hypothesis:* Selecting the most likely hypothesis for the solution of a given problem may involve special skills such as analysis and interpretation of data and judging its significance for the immediate problem. The selected hypothesis are again tested to find out the truth. The experiments should be performed and finally the evidence should be presented in the class. In several instances the reported results will be seriously questioned on the basis of inadequate controls or careless manipulation. The proof of the worth of a hypothesis lies in its ability to meet the test of its validity. If it fails to meet the test of validity, it must be modified or rejected.

8. *Drawing conclusions and Making Generalisations:* This step in the problem-solving process follows closely the preceding step of testing the hypothesis. In this step the ability of judging the consistency of the generalisations and establishing the principles and generalisations in the light of the tested evidence is required. When a hypothesis is sustained by logical tests, it provides the basis for drawing generalisations or conclusions.

9. *Application of generalisations to New Situations:* It is essential that the students should supply the generalisations to new situations which are close to their life experiences. This will enable them to bridge the gap between artificial class situations and real life situations. It should also enhance the probability of transfer for the several abilities of problem-solving which have been sought as desired outcomes.

Limitations

1. This method is time-consuming, when we use this method, the ground to be converted has to be sacrificed to the accomplishment of certain other outcomes.
2. No textbooks written on these lines are available.
3. Gifted teachers, who can employ the method efficiently are not available.

Now an example will be given to illustrate the application of the method in the teaching of physical sciences.

Illustration of Problem-Solving Method

A cylindrical coil of insulated wire is taken and the ends of the wire are connected to a small bulb. Now a bar magnet is rapidly introduced in the coil. It is kept inside the cylindrical coil for some time and then it is rapidly withdrawn. The students observe that the bulb glows only when the magnet is introduced or withdrawn but it does not glow when it is kept stationary inside the coil. The following questions may be asked to the students:

1. Why does the bulb glow when the magnet is introduced inside the coil?

2. Why does the bulb glow when the magnet is withdrawn from the coil?
3. What is the source of current due to which the bulb glows?
4. Why does the bulb not glow when the magnet is inside the coil but is not moved?
5. Why does the bulb glow for a short time only?

Some more questions may be asked depending upon the situation. As the students are unable to answer the above questions, they are faced with problems.

Defining the Problem

The students decide to find out reasons for what they have seen. They are asked to define the problem in a concise, definite and clear language. The students may define the problem in the following way:

1. Study of the source of current in the coil when a magnet is introduced in it.
2. Study of the source of current in the coil when a magnet is withdrawn from it.
3. Study of the reason why the current produced in the above cases is only for a short time.
4. Study of the other sources due to which such current can be produced.
5. Study of the reason why there is no current when the magnet is inside the coil but it is not moved.

Analysis of the Problem

The students note down the key words and phrases in the stated problem which furnish clues to its solution. In the above problem the key words are "Source of current when magnet is introduced or withdrawn" and "No current when magnet is stationary inside the coil". Other key words are "Current is only for a short time". These words, phrases or sentences give a clue that source of current is somehow connected with change in the magnetic field.

Collection of the Data for all Possible Clues

The students consult some textbooks and they may decide to go on a field trip. The field trips may be planned to some power stations where they will be able to gather information as to how electric energy is produced or electromotive force is developed due to change of magnetic flux. They will also be able to see some transformers.

They may perform some preliminary experiments themselves some of which are given below:

A cylindrical coil of insulated wire is taken and the ends of the wire are connected to a sensitive galvanometer. If a magnet is introduced or withdrawn from the coil, there is a deflection in the galvanometer.

If the magnet is introduced or withdrawn rapidly, the deflection is greater.

Another cylindrical coil of a smaller diameter than the first is taken and it is connected to a battery, a key and a rheostat. This coil is placed in the hollow space of the first. If a key is pressed or it is opened, there is a deflection in the galvanometer in both the cases but the direction of deflection in the galvanometer is opposite. When the key is pressed, there is deflection in the galvanometer when the coil is introduced inside the first or when it is withdrawn.

Interpretation of the Data

Now the students arrange and organise the data. They note down if there are any similarities in the results, some of which are given below:

1. When a magnet is introduced in the coil magnetic lines of force passing through the coil increase and deflection in the galvanometer is noted which means that an induced e.m.f. is produced.
2. When the coil, connected with a battery is introduced or its key is pressed, the magnetic lines of force passing through the coil connected with galvanometer increase. It is found that again there is a deflection in galvanometer or an induced e.m.f. is produced.
3. When magnet is withdrawn from the coil, magnetic lines of force decrease. Deflection in the galvanometer is seen showing that an induced e.m.f. has been developed.
4. Similarly when coil connected with battery is withdrawn or its key is opened, magnetic lines of force decrease. The deflection in the galvanometer in this case also shows that an induced e.m.f. is produced.
5. The direction of deflection in the galvanometer produced due to increase in lines of force is opposite to the direction of deflection when lines of force passing through the coil decrease.
6. If the magnet is introduced or withdrawn rapidly, deflection in the galvanometer is greater.
7. If the coil connected with battery is withdrawn or introduced rapidly, deflection in the galvanometer is greater.

Similarly all the data collected during field trip or by other sources are also interpreted and clues to the solution of the problem are found out.

Formulation of Tentative Hypotheses

After the data have been collected and interpreted, the hypothesis are formulated, some of which are given below:

1. When the number of magnetic lines of force passing through a closed circuit decreases, an induced e.m.f. is set up in the circuit.

2. When the number of magnetic lines of force passing through a closed circuit decreases, and induced e.m.f. is set up in the circuit.
3. The direction of current at the time of increasing the lines of force is opposite to the current produced while lines of force are decreased.
4. If lines of force passing through a coil are increased, or decreased rapidly, e.m.f. produced is greater.
5. If the number of turns in secondary coil are increased, induced e.m.f. is greater.
6. If the number of turns in secondary coil are decreased, induced e.m.f. is greater.

Selecting and Testing the Most Likely Hypotheses

Here, through discussion, it is made clear to the students, that, unless during one experiment only one factor is varied, and others are controlled, the cause of e.m.f. or the factors on which e.m.f. produced depend cannot be known with confidence and final conclusions cannot be drawn. Now the students may perform the following experiments.

Apparatus to be Used

A cylindrical coil of insulated wire, a battery, a key and long reheostat are all connected in series. This coil is called primary. Another cylindrical coil of larger diameter than the first is connencted to a sensitive ammeter. This coil is secondary. A stopwatch is used to note the time.

FIRST EXPERIMENT

The primary coil is placed inside the hollow space of the secondary coil. The key is pressed and current in the ammeter is noted. The sliding piece of one rheostat is moved from one end to the other and current in the secondary is noted by the ammeter. The time taken in moving the sliding piece is read from the stopwatch. The sliding piece is moved with different speed and every time the current in the secondary coil and the time taken in moving the sliding piece is noted. It will be found that the induced current or induced e.m.f. is proportional to the rate at which sliding piece is moved or the rate with which the lines of force passing through the coil are increased. In this experiment sliding piece is moved to decrease the resistance or increase the current in the circuit.

SECOND EXPERIMENT

The key in the primary coil is openend. It will be seen that the current produced is opposite to the direction of current produced in first experiment and so the ends of wires connected to the binding screws of the ammeter are changed. The current is noted by reading the

ammeter. Now the sliding piece of the rheostat is moved with different speeds from one end to the other, and the time taken in moving the piece, and current produced, are read in each case. Each time the sliding piece is so moved that the resistance of the circuit is increased or current in the circuit is decreased resulting in the decrease of lines of force. Again it is found that the induced current or induced e.m.f. is proportional to the rate at which sliding piece is moved or the rate at which sliding lines of force passing through the circuit decrease. In both the above experiments the number of turns in the secondary are kept constant.

THIRD EXPERIMENT

In this case the resistance and number of turns in the primary coil is kept constant throughout and number of turns in secondary are changed. First of all n_1 turns are taken in secondary, and note the current when the key of the paimary coil is pressed. Now the number of turns in secondary coil are changed to n_2 and the current is noted when key is pressed. Similarly, for several values of turns in secondary coil, current is read when key in primary is pressed. It is found that the induced e.m.f. is increased by increasing the number of turns in the secondary.

Drawing conclusions and making Generalisations

Now the following conclusions or generalisations are drawn:

1. When the number of magnetic lines of force or magnetic flux passing through a coil in circuit alters, an induced e.m.f. is set up.
2. The magnitude of the induced e.m.f. is directly proportional to the rate at which the change of magnetic flux takes place.
3. The magnitude of the induced e.m.f. is directly proportional to the number of turns in the secondary coil.
4. An increase in the number of lines of force linked up with the circuit induces an inverse current while the decrease in the number of lines of force induces a direct current in the circuit.
5. The current continues only for the time, the change in the number of lines of force actually takes place.

Applications to New Situations

The students now study the application of these principles in an induction coil in which an induced e.m.f. of very high voltage is produced by rapidly making and breaking primary current of low voltage.

The applications of the above conclusions are found by the students in a dynamo by which electric energy is generated. The students study the application of the principles in transformers also.

From the above discussion, it is quite clear that problem-solving/scientific method involves a definite and set procedure of attacking the problems and finding their solution. The process of building up a set of principles through problem-solving techniques in an inductive process while the application of the principles to new situations is a deductive process in nature. Hence problem-solving method is also called inductive-deductive method.

From the standpoint of learning, this method is very valuable as all the laws of learning find their application in the process. This process is also better from another point of view, as it is much easier to remember a given fact of truth when it is related to some broad generalisation than to remember it as an isolated element.

The example given above to illustrate the method clearly shows that it is not necessary to abandon the prescribed course while applying this method but much of the present prescribed course can be taught by scientific method with a shift of approach. It is true that this method is time-consuming but even if some experience of this method is given to the students at different times in one year, they will be of an immense value.

HEURISTIC APPROACH FOR PHYSICAL SCIENCES

As early as 1790, Priestley suggested that Chemistry should be introduced as an educational subject, and that teaching methods should be based on investigation so that pupils themselves discover the facts. Pestalozzi, Herbert Spencer and Rousseau were the other advocates of similar teaching methods. According to Herbert Spencer, children should be led to make their own investigations and to draw their own inferences. They should be told as little as possible and induced to discover as much as possible.

The term Heuristic comes out of the Latin word *heurisco* which means 'to find out'. Prof Armstrong defines heuristic method in the following way: "Heuristic method is a method of teaching which involves our placing the students as far as possible in the attitude of a discoverer." Armstrong considered that Chemistry lessons should be made up of definite tasks. These should be in the form of problems which each pupil works out experimentally.

Principles of Heuristic Method[2]

Every science lesson should be in the form of an inquiry. Work is scientific only when it springs from a desire to know from our own knowledge some definite thing, concerning which our curiosity has been moved.

Knowledge is only useful when it is obtained from personal observation. The pupil, rarely, if ever, uses a textbook and he should be put in the position of an original discoverer.

2. Newbury, NF, *Teaching of Chemistry in Tropical Secondary Schools*, Oxford University Press.

Young pupils are delighted when told that they are to act as a band of young detectives. In studying the rusting of iron they may be told that a crime has been committed on the valuable and strong iron to change it into brittle dust. They are interested to find out if it is murder (something outside the iron), or suicide (changes on its own accord).

Problems must be carefully graded and then pupils should be allowed to walk around the laboratory and get help from their companions. Qualitative work should be introduced quite early in the course.

It must be noted that Armstrong's methods are occasionally misunderstood. His idea is not that the pupils should discover the cause of a reaction but that they should find the general conditions under which it occurs.

The knowledge acquired by correct use of the heuristic method is thorough, for all the information is obtained from direct contact with apparatus and chemicals. Independent and individual endeavours are the basis of learning. Interest is aroused in common objects, as well as natural phenomena.

Techniques of Applying Heuristic Method

A problem is set in the class and each child is made responsible for finding out the solution for himself. The child can acquire information from different sources. The students get some guidance from the teacher and some instructions may also be given by the teacher. The students follow the instructions and work themselves. However, the teacher should not expect too much from the students. He should try to elicit everything from the students. The teacher should put some questions which will stimulate the pupils to know more and lead them on the right track. They are led to interpret the data correctly and to draw their own conclusions. If the conclusions drawn by the pupils are wrong, they should be asked to repeat the experiment and try to collect more data which may lead to right conclusion. Pupils learn to balance and weigh words and phrases as well as objects. Armstrong claims that specific benefits are derived from his methods, which develop moral and intellectual character. The peculiar advantage of the heuristic method is that it encourages the young research worker (the pupil) to develop the attitude of the experienced research worker, by carrying out experiments under similar conditions.

Criticism

Heuristic method lacks vitality, since it concentrates on the arrangement of facts and a systematic training in experimental methods.

The method cannot be applied to the discovery of fundamental physical and chemical laws. These can only be verified and illustrated.

The heuristic method is effective when a great deal of time is devoted to a small section of the physics/chemistry course, but it is

unsuitable in these days when general principles are taught. Again some pupils are familiar with more chemical facts than others. In a practical problem, some know the result before the experiment is begun. For example, in one school, parallel classes which had completed two terms were to begin experiments on the composition of water. A written test was given asking which elements are present in water. Twenty-one out of sixty knew that water was made up of oxygen and hydrogen and seven pupils knew its formula.

Probably most criticism centres round the idea of putting the child in the position of an original discoverer. Theoretically, this idealistic scheme is attractive, but it is not possible in practice.

Merits

The following are the merits of the method:

1. It develops the power of observation and pupils gain confidence.
2. The method develops the power of reasoning ability and interpreting the data correctly.
3. It cultivates manual dexterity and habit of handwork is encouraged.
4. Learning is through direct experience, it is more effective.
5. The facts learnt are retained for a longer time because they are the results of children's own efforts.

Difficulties and Limitations in the Present Situations

1. As the students at the school level are immature it is too much to expect from them that they can discover everything by themselves.
2. Textbooks, guide books and teachers' guides written on these lines are not available.
3. It requires a well-equipped laboratory and library.
4. Very slow progress can be made in the classroom teaching and so the present syllabus cannot be covered in time.
5. Only qualified and trained teachers can apply this method successfully.
6. Weak students may feel difficulty and copy the observations of bright students.
7. Problems presented should be carefully graded and the maximum easy to difficult should be followed strictly. Problems should be interesting. All this demands hardwork and skill on the part of the teacher who is already loaded in our schools.

PROJECT-METHOD

In lecture-demonstration and Laboratory and Problem-solving methods individual approach is made. Either the student takes an active part, or the teacher is the main figure. Individual student's approach is important because opportunities are provided to students

to learn in accordance with their individual differences. This would permit a student to progress through the work at his own rate.

It may be pointed out that when the individual approach for teaching Physical Sciences is used extremely, many socialising values of discussion and group work are lost. This deficiency is fulfilled by the project method.

Demonstration method is based on the principle of 'learning by observation'. Laboratory method is governed by both: learning by observation and learning by doing. Problem-solving method takes into account, two cardinal principles of laboratory method along with third principle, learning by trial and error. Finally the Project Method stresses on group activity and develops qualities of leadership. It works on the following principles: learning by observation, learning by doing, learning by trial and error, and learning by living.

The last principle clearly signifies the fact that man is a social animal who cannot learn in isolation, but always learns better in a group or society in which he is placed. If an individual wants to live harmoniously and efficiently in a society he should be provided with opportunities in schools to solve a bit of similar problems which he will have to face in actual life.

Definitions of a Project

A project is a bit of real life that has been imparted into the school. This definition narrates the nature of project and stresses that it should be related to actual life or experiences of the pupils.

'A Project is a problematic act carried to completion in its natural setting. In order to foster the qualities of leadership among pupils, opportunities of group activities should be afforded to the class during the course for the completion of the project.

'A Project is a wholehearted purposeful activity proceeding in a social environment'.

By analysing the above definitions we come to the conclusion that a project has some purpose and it requires planning beforehand. The purpose is achieved in a social or a real, natural environment created in the school.

A child is the centre of all activities for a school, e.g., curriculum and he should be provided with a democratic atmosphere so as to think independently in order to acquire knowledge.

The above definitions provide a brief idea regarding the steps involved in Project Method. The teacher poses a problem to the class. The problem should be correlated with actual experiences of the children. Students plan up and complete the selected activity in natural and social setting. At the end pupils evaluate themselves and record the whole procedure involved in completion of the project under the guidance of the teacher.

Steps Involved in a Project

1. *Providing a situation*: The teacher should create situations fully of scientific enquiry that the students may be tempted to pick up and solve the problems. This is an important step which will motivate pupils to take up the project willingly as their own.

2. *Selection of a project:* When the students become interested to pick up and solve a problem, the teacher gives a number of alternative suggestions for the selection of a project suitable to their understanding level and other mental capacities. Discussion follows among students under the supervision of the teacher who makes the purpose of the project clear to them.

3. *Planning:* Teacher initiates the discussion among students through suitable questions for the execution of the project. Pupils discuss the plan under the guidance of the teacher who informs them about good and bad points of the plan in accordance with the need. After finalisation, the students write the method decided upon by them for the execution of the project.

4. *Execution:* The whole class is divided into a number of groups, depending upon the activities involved in the project. Each group selects a leader who is responsible for the completion of a particular activity assigned to him. The teacher assigns the work to each student according to his capacity and interest. The whole work is supervised by the teacher who guides, encourages and watches the progress of pupils and gives instructions from time to time.

5. *Evaluation:* In order to check whether the objectives of project have been achieved or not, a review of the whole project is carried out by pupils in order to know the mistakes committed by them. This gives an idea of the extent to which the success has been achieved.

6. *Recording:* Students may be advised to record a brief summary of the project right from the very beginning to the completion for future guidance. They should also note down the mistakes committed during their evaluation.

In short, the project method makes a teacher open up a new area of investigation and the class then organizes itself into small groups to investigate the various problems which have been defined. Each group selects a group leader who becomes responsible for the work of the group. Various groups then carry on whatever activities seem valuable for the solution of the problem at hand. From time to time the class is assembled by the teacher for general instructions or for hearing progress reports from the various groups. At the close of the unit, the class assembles to hear the group reports, see important demonstrations, pictures, slides, to take part in the discussion and the organisation of the material.

Role of the Teacher

In the selection of the project, the teacher should have a complete idea regarding the standard, average intelligence, maturity, age and previous knowledge of the students from the point of view of its feasibility. The teacher should be fully confident that completion of a project inculcates scientific attitudes in the pupils and gives them training in scentific methods. He should see that the project is economical both from the viewpoint of money and time. The teacher should create a democratic atmosphere in the class by acting as a guide and a friend of the pupils. Sufficient opportunities should be given to all students for participation in general, and to shy students in particular, so that contribution from every side is available towards the success of the project.

Illustration of Project Method

The teacher will demonstrate to the students how to emphasise the importance of air in daily life.

He will take two jars, one of Co_2 and another of air, put two butterflies in each of the two jars and keep them before the class. After a few minutes the students will observe that a butterfly in the jar of Co_2 is not alive whereas in the other jar is alive. Thus pupils will conclude that air is very essential for the existence of living things.

This will motivate the pupils to take up the study of air. Discussion will be initiated in the class by the teacher through suitable questions, asking students to discuss the different units of the project, class will arrive at conclusion to study the topic under the following sub-units:

1. Air has weight and it exerts pressure.
2. Importance of air pressure in daily life.
3. Simple instruments which work on the pressure of air.
4. Determination of the composition of air.
5. Classical experiments of Priestley and Lavoiser to determine the volume of oxygen in air.
6. Combustion, respiration and rusting.
7. Photosynthesis; relationship between respiration and photosenthesis Co_2 cycle.
8. Air as a source of energy in nature.

Class will be divided into eight groups or so depending upon the number of students and sub-units of the topic. Each group will have a leader, responsible for the activity. Students will be guided to consult reference books and periodicals. They should go to a library where they will learn the use of index cards to search out books and develop the ability to use books effectively so as to secure exact information.

Boys will be asked to collect information, prapare charts and models, collect pictures, secure first hand information by experiments. Teacher keeps a close watch on students so that they are not led astray. He guides them and assembles the class from time to time to check their progress.

In the evaluation of each project, the group leader submits the report, presents chart, model-picture, etc., and performs the experiments, if any, before the class.

4

LABORATORIES AND KITS FOR PHYSICAL SCIENCES

In designing physical laboratories for high school the major consideration to be borne in mind is that the lay-out should be flexible. The patterns of physics and chemistry teaching and changing and a rigid design, which may be suitable for the present needs, may be found inconvenient in the future. A maximum of adaptability should be looked for. On some occasions the pupils will be working in groups at benches, on others they will have to be grouped to watch a demonstration and may need to make notes during this, so that they should have sufficient space available for writing purposes. There will be times when an area of clear floor space is required which is visible to all, or sometimes several smaller clear areas are wanted for ripple-tanks, etc., and the final arrangement of the laboratory should make all of these possible.

To meet these conditions the benches in the classroom must be movable to make clear space possible. Strong tables, therefore, seem preferable to the traditionol long benches, which should be sufficiently stable to afford firm surfaces which are free from vibration and not easily displaced by knocks. It is not convenient to provide services on such tables, but this difficulty can be overcome by providing ample services on side benches and moving the table up to these points when services are required. Possible arrangements are described in a later section.

The difficulties in demonstrations can be overcome by providing a demonstration area in the laboratory, which can have the form of tiered seating, provided with writing benches and of sufficient size to accommodate a full form. The remainder of the laboratory is then free for practical work and this can be made to alternate with demonstrations or discussions. This avoids any necessity to divide the work into 'practical' and theoretical' sections which can be very difficult to arrange.

TABLES[1]

Tables may be large and fixed or small and mcvable, while a

1. AMA, AAM, ASE, *Teaching of Science in Secondary Schools*, John Murray, London.

combination of both sizes is often used—convenient sizes for tables are 4ft. × 2ft. for movable ones, or, if larger tables are preferred, 5ft. × 4ft. whatever the final choice is made, one fixed bench, preferably along the windowed side of the laboratory, is most useful. The table tops should be flat, with an overlap of 2 in. to 4 in. all round, and in an elementary laboratory it should be 2 ft. 10 in. from floor to table top, the legs being stout to ensure rigidity. There is a general opinion that cupboard space below tables should be avoided, but that a single row of shallow drawers, is valuable for storage. Setback drawers allow writing in comfort and permit the easy use of bench clamps where apparatus has to be held rigidly.

In many schools the pupils carry around a considerable number of books and satchels of various sizes. If these are deposited on the floor of the laboratory they are a nuisance and can even be the cause of accidents. If a shelf, the same size as the top of the bench, is provided with a gap of around 8 inches between the top of the bench and the shelf, this space can then be used for the storage of books.

When fixed benches are being considered for a laboratory it would be worthwhile for the physics teacher to examine some of the proprietary products which are now coming on to the market. For example, one particular manufacturer is producing octagonal benches which give a good working area and have the advantage of incorporating a considerable amount of storage space, including provision for long pieces of apparatus, and designed with Nuffield Physics in view. Apart from the considerable disadvantage of being fixed benches, with the attendant lack of adaptability, they give convenient working positions. They can also be used with trolleys designed to fit the spaces between them and to give large area working surfaces. Benches based upon metal framework are also commercially available.

SERVICES

A. *Water*: Two or three sinks will be found adequate for a physics laboratory and these should be located on side benches and well separated from each other to allow simultaneous access by groups of pupils. Sinks are often too small and 24 in. × 18 in. × 18 in. deep should be a minimum size. One of these sinks should be provided with a hot water supply and this is conveniently done by a sink heater.

In any area the taps must be fed from a tank, because of irregular water supply and sometimes because of insufficient pressure to operate filter pumps.

B. *Gas*. If gas points are fitted to working benches these should be recessed in order to leave a clear working surface, but it will usually be found sufficient, where movable tables are used, to have gas points on the side benches only, and to move tables up to these when gas is needed. In the majority of experiments in which gas has to be used, it is possible to arrange that one gas supply will accommodate two

or more groups of pupils, and the provision of gas points in physics laboratories has tended to be excessive in the past.

C. *Electricity*. Low-voltage supply is an essential requirement for a physics laboratory. Besides allowing pupils to perform with safety all the elementary experiments in the study of electricity, it will also find applications in other parts of the work, for lighting low-voltage bulbs, for operating ray-boxes, etc. The voltage must be variable in steps, and a current of 3·4 amperes must be available at each working point. Both A.C. and D.C. supplies must be possible; occasions may arise when it is desirable to have both of them at the same time.

It has been the standard practice to supply low voltage from a central unit, either of a rectifier type or from batteries. This method is subject to the following limitations:.

1. Voltage fluctuations are difficult to avoid. When one group switches off then other groups experience a voltage rise which may be sufficient to burn out bulbs or seriously affect electrical experiments. Similar voltage falls occur when one or more groups switch on.
2. It requires a complicated installation to make different voltage available at different points.
3. The current to be supplied from the installation may be of the order of 60 amperes and fuses or out-cut switches are a necessity.
4. Ring-main wiring is not satisfactory and small groups of working spaces must be wired directly to the supply by cable of adequate size. This becomes an expensive installation and, even when carefully designed and installed, is liable to be less than satisfactory.

It is therefore strongly recommended that low-voltage should be supplied by using separate units for each working space and there are now a variety of such units available. The overall cost will be considerably less than that of a central unit and its wiring, and the separate units possess a degree of versatility which cannot be approched by the former system. Each working group has its own supply, which can be A.C. or D.C. and is completely unaffected by circuit alterations of neighbouring groups. Both A.C and D.C. are simultaneously available where this is required and the voltage can be selected and adjusted according to requirements. This system is now in use in many Public and Central schools and the reports from these schools state that they find it fully satisfactory and much superior to centralized supply.

If this low-voltage system is adopted it will be necessary to pay particular attention to the number of main power points available, but even where the central supply system is used, there is a steadily increasing demand for main power points as the variety of apparatus

needing such power is growing with the new apparatus coming into use.

STORAGE

Storage of apparatus is a serious and growing problem and the storage provision in the majority of school physics laboratories is quite inadequate. Schools using the Nuffield apparatus in particular require the space to store a considerable quantity of bulk equipment and, as stocks are built up, there is a steadily increasing pressure upon space which might have been thought previously to be sufficient.

A combined preparation room and store is certain to prove unsatisfactory and it is strongly recommended that teachers of physics should insist on the provision of storeroom of generous size in addition to a preparation room. A storeroom which is merely a large cupboard is not sufficient and an area of at least 400 sq. ft. is required, but it could well be larger.

The apparatus to be stored will vary in size and in shape; there will be sets of small pieces of apparatus, magnets, ebonite and polythene rods, etc., for which shallow drawers are convenient, and other sets of apparatus of slightly larger size such as ray-boxes which require rather deeper drawers. It is suggested, therefore, that one wall of the storeroom should have cupboards containing trays of three different depths. Such trays enable the whole volume of a cupboard to be utilised, whereas the conventional cupboard with a shelf uses only a fraction of the total volume for actual storage.

A convenient system is to have trays of depths $1\frac{7}{8}$ in. $3\frac{7}{8}$ in. and $5\frac{7}{8}$ in. A normal cupboard door is fitted in front of the trays.

Plastic storage trays are now available and are a cheaper alternative to the scheme illustrated, although not possessing the same versatility. The relative cost and convenience of the two systems should be examined while making a decision.

A tray system can also be extended to cupboards in the laboratories and in the preparation room which will permit the storage of a larger amount of the smaller pieces of apparatus in a comparatively small storage volume.

Shelves with adjustable spacing should be fixed above the cupboards in the storeroom. Provision must also be made for the storage of radio-active materials and care must be taken to ensure that this complies with the official regulations for these materials.

BLACK OUT

For most of the work in physics a dim-out is satisfactory and gives more pleasant working conditions than a complete black-out. Venetian blinds are simple to use, provide a rapid dim-out with control of the illumination of the laboratory, allow windows to be left open to give satisfactory ventilation in summer and give a sufficient degree of

darkness for almost all the work in optics and for many of the visual aids. Unfortunately, experimental work on colour requires complete darkness to be really satisfactory and darkness is also needed for the showing of films. This complete darkness can be provided by using blinds running in frames over the windows. The most satisfactory arrangement is to have both facilities, venetian blind can be fitted close to the inner surface of the windows and a black-out blind in its frame can be fitted to the wall immediately surrounding the window.

In any laboratory in which complete black-out is to be used arrangements should be made for satisfactory ventilation. A room containing a complete form and having all windows and doors closed becomes unpleasantly hot and humid in quite a short time. Efficient and reasonably silent extractor fans should be fitted to all laboratories in which black-out will be used.

VISUAL AIDS

The range of visual aids available is increasing and find application in physics teaching. Consequently, every laboratory must be provided with a suitable screen which is convenient to use and can easily be removed when not in use.

Demonstration Bench/Table

In the majority of existing laboratories a long demonstration bench, raised on a dais, is provided. The length is considered necessary in order to permit several different demonstrations to be prepared and set out ready for use, and the dais raises the teacher above the level of the class, rendering supervision easier. It is worthwhile considering how convenient this arrangement is, and whether a better alternative can be found. There are several disadvantages of this system.

1. The system tends to put demonstrations into a position of isolation from the practical work done by a class leading to an artificial division of science teaching into practical and theoretical work. The pupils are observers and not participators.
2. It occupies a considerable amount of space, reducing the area available for practical work by the class.
3. The height of the bench adds to the difficulty of enabling all pupils to get a clear view of demonstrations and they may not be able to see in sufficient detail to have a clear idea of what is being shown. If a class is gathered round such a bench, the front row can see clearly but it is difficult to arrange that the rear ranks have an uninterrupted view and pupils may end up sitting on benches or standing on stools.

One way of overcoming this difficulty is to have demonstration area with tiered seating, so that pupils can see clearly and are also able to make any notes required. If such a demonstration area is not used it is recommended that the dais should be dispensed with and that the

demonstration bench should be of the same height as the other benches in the laboratory.

It is also recommended that a bench in the form of a broad L shape should be considered in place of the standard long bench. This has the following advantages:

1. It does not occupy such a large working area of the laboratory.
2. The whole bench is more compact, is within more convenient reach of the teacher and avoids the necessity of his moving from end to end to demonstrate.

The bench can be made in two sections with a space into which a trolley will fit.

Apparatus can be set up beforehand on the trolley ready for the demonstration and wheeled into position when needed, and, if further demonstrations are to be given the first trolley can be removed and replaced by others when they are required. If a flap is made which will fit across the trolley space this will enable a continuous flat surface to be obtained when this is needed. This flap can be hinged or can be fitted on to supports on the side of the trolley space; it will also serve the purpose of supplying a writing-space for the teacher. The solid sections of the bench should be supplied with drawers for storage of frequently used small items of apparatus, and it is suggested that one of these should be a long shallow drawer to accommodate wall-charts, etc.

At least two double main points should be available.

Advanced Physical Laboratories

Since the laboratory will be used by smaller sets it could well be somewhat smaller in size and 750 sq. ft. is probably adequate. The smaller size also removes the temptation to time table junior forms in this laboratory as well; the advanced laboratory will contain more expensive and more delicate apparatus and there is a considerable risk of damage occurring if junior forms are followed to use it.

Even if schools possess a science library, reference books must be available in the laboratory to cover each branch of the subject. These will be used during practical sessions; if a display area is provided outside the laboratory the bookshelves can well be made part of this.

General Points

1. The system of locks on doors, cupboards and drawers will require careful attention. Locks tend to be fitted on far too many drawers and cupboards; which provide no real security, can normally be forced open with ease and most of them are unnecessary. A few cupboards should be lockable, but there seems little point in having a different key for each one. Too often a new laboratory contains a large number of locks with a multiplicity of

keys, and this means that either the keys are left permanently in the locks or else a carefully labelled key-rack is needed. A master-key which will open any cupboard or drawer in emergency is also required.

2. A large clock with a seconds hand should be mounted in a prominent position in each laboratory. This is satisfactory for most timing purposes in the laboratory and avoids the extensive use of stop-clocks.
3. All test milliammeters with large dials, mounted on the wall near the demonstration bench are useful. Leads can be taken to a terminal block mounted just before the surface of the demonstration bench, and with the use of shunts or resistances currents and voltages of all sizes can be clearly shown.
4. The floor of a physics laboratory must be solid and free from vibration. Board floors are particularly unsuitable in this respect.
5. Painting should be of a light colour to give a bright and cheerful appearance, and as much of the wall surfaces as is convenient should be covered with pin-board for display purposes.

Introductory Science and Dual-Purpose Laboratories[2]

It is often necessary to plan laboratories for general science teaching. In small schools economy may force the adoption of dual-purpose laboratories. But it is desirable to emphasise, however, that in our view really adequate science accommodation for academic courses must involve separate laboratories for chemistry, physics and biology.

There is at present little experience to guide the design of either general-purpose or dual-purpose laboratories, and all that can be attempted here is to offer some suggestions which may assist those who have the opportunity of experimenting.

Dual-Purpose Laboratories

A dual-purpose laboratory could be designed (a) for both chemistry and physics, (b) for both physics and biology. With two such laboratories it should be possible for any school of moderate size to arrange a complete general science practical course. All the experimental chemistry would be done in one laboratory and all the experimental (indoor) biology in the other, the physical work being divided between the two laboratories. The need for a laboratory assistant would be more than usually urgent. The organisation of practical work would be made easier if the same teacher were responsible for the whole of the general science work of one form.

The essential requirements for a dual-purpose laboratory appear to be:

2. AMA, AAM, ASE, *Teaching af Science in Secondary Schools*, John Murray, London.

1. Large working space,
2. generous storage accommodation,
3. flexibility of furniture arrangements,
4. adequate equipment.

In view of the many uses of the room, the planning becomes largely a matter of finding the most generally suitable to differing requirements. For this reason special fittings of all kinds must be considered with exceptional care, particularly in cases where they might interfere with the conduct of work for which they were not specially designed.

Accommodation should be planned on a generous scale, and the science master should press for the largest possible area, square or almost square in shape. The department of Education and Science figures for bench width and elbow room should be regarded as absolute minima and every attempt should be made to make passageways as wide as possible. It is a safe guiding principle to reduce as much as possible the distance which a student will have to move in the course of his work.

If any laboratory designed for the teaching of more than one branch of science, it is desirable to allow adequate bench space for reserve purposes. If the laboratory is being used for a physical experiment then the reserve bench can be used to store biological material required for the next lesson. Such bench space is also useful for storage of apparatus for experiments which cannot be completed in one period. Some teachers prefer wide shelves for this purpose.

The following general remarks on the requirements for dual-purpose laboratories may be added:

1. Some provision for demonstration is essential. In the absence of a lecture room this may be met by the provision of a demonstration bench. The fittings need not be elaborate, but should include supplies of electricity, gas and water, a sink, and a cupboard.
2. It is desirable to have one or more benches fixed to the wall. The room should also contain movable tables of the same height. The tables could be rearranged or joined to the benches as required. Two benches might be joined end to end by a removable or hinged flap. Such arrangements of furniture, while suitable for physical and biological work, are not suitable for chemistry.
3. The height of the benches is a real difficulty. It seems that the best solution is to make them rather lower than is usual for physics and chemistry and rather higher than is usual for microscope work, with a corresponding adjustment in the height of the stools. The height of the pupils using the furniture must also be borne in mind.
4. The problem of storage is likely to be acute and needs very detailed consideration. Adequate and convenient storage rooms are

valuable but they do not solve the problem. There must be storage space in the laboratory as well.

5. The number of sinks required depends largely on the use to which the laboratory will be put. A safe method would be to arrange the number of sinks to suit the subject needing them most.
6. In a general laboratory there is much to be said for supplying gas, water and electricity to points along the walls, but the usual precautions for the isolation of electrical points from water and gas pipes must be observed. Additional supplies could also be picked up from covered wells under the floor, though some science masters stongly object of this arrangement. Temporary connections from gas or electrical points to distributing centres on benches or tables have proved effective in many schools.

   North lighting, with the windows coming down to bench level and reinforced by top lighting, is helpful for biology work, and at least one clear wall would be useful for simple experiments in mechanics.
7. There should be provision for the use of films, lanterns, epidiascopes, radio and possibly television.

Laboratory Rules for the Students[3]

Students should bear in mind the following general rules:

1. Nothing is to be removed from the laboratory. Apparatus and other material in the laboratory is the property of the school.
2. Laboratory equipment and material is for use only in the laboratory.
3. Apparatus and materials must be used only for the purposes sanctioned by the teacher incharge. In any experiment, the pupils must stick to the instructions given by the teacher and must not go beyond them.
4. Any mishap, for example, cut, burn, chemical substance in mouth or eye, or on clothes, must be reported to the teacher at once.
5. Breakage and faults in equipment must be reported immediately to the teacher.
6. Loose and obscure labels must be reported to the teacher at once. (This will avoid mistakes).
7. It is essential to make sure that the name on a label is exactly the same as that of the object or substance required for particular experiment.
8. Bottles must never be held by the neck or stopper.

3. Saunders, H.N., *The Teaching of General Science in Secondary Schools*, p. 274.

9. Stoppers from bottles should be removed in the proper way and replaced at once. A stopper must always be put on the right bottle. There is otherwise a risk of introducing impurities and of causing an unwanted chemical reaction.
10. The smallest convenient quantity of a substance is all that should be used in any experiment. It is economical.
11. A substance taken into mouth accidentally must be spat out at once and mouth washed out with water.
12. Nothing should be tasted without definite instructions from the teacher.
13. Acid or Alkali on skin or on clothing must be washed off at once with plenty of water.
14. At the end of an experiment, apparatus must be left clean and tidy in the place where it was found.
15. Solid objects must not be put into a sink. There is danger of blocking the water-pipe.
16. Wastage of gas, water and electricity must be avoided. When supplies are not in use, all taps and switches must be turned off. It is economical and risk of accidents is also reduced.
17. The laboratory, working benches and tables and equipment must be left clean, neat and tidy before leaving it.

Importance of Science Kits for Teaching Physical Sciences

In the present economy of the country it may not be possible for some time to provide individual laboratories for teaching science subjects at the school stage. It has, therefore, become necessary to devise certain kits where all facilities for demonstration and experimentation are available to the teacher in a compact and portable form which can be used in any classroom.

The science kit is a science mini-laboratory. It serves the functions of a laboratory where well-equipped laboratories are not available. It contains all the items required for various experiments and demonstrations suggested in the textbook or teacher's guide. In fact a resourceful teacher can do much more than described.

For some experiments there are certain items which can be procured locally and their cost is very low. For example the teacher may need items like thread, a sheet of paper, a pencil, sand and a few stones, etc., which have not been provided in the kit. Such items are not difficult to get from the local surroundings.

The school science experiments can be grouped under two headings:

Demonstrations and *Pupils' Experiments*

For demonstrations usually only one set of single apparatus is required whereas for pupils to conduct experiments the items have to be 15-20 in number so that a small group of pupils can perform the experiments simultaneously.

The kit is primarily meant for demonstrations. But it also contains items for individual laboratory work though in one number only. However, since items are usually simple they can be multiplied by students themselves with the help of the teacher.

All the items included in the kit are placed in trays to make it easy for a teacher to take out the required ones. The kit box is not so heavy and can be taken from one classroom to another, if necessary. The top of the box can also be used as a base and a raised platform for doing some demonstrations especially if the teacher's table is not high enough.

While preparing demonstrations, the teacher should keep in mind a few important points:

(*a*) The main parts of the equipment and its arrangement are clearly visible to all the pupils.

(*b*) During the demonstrations, only items directly related to the experiments are displayed. Do not open the other trays.

(*c*) The demonstration is shown without haste and in steps with the teacher explaining each step clearly to the pupils.

(*d*) All precautions are taken to make the demonstration secure.

In all the demonstrations participation of the pupils is highly essential. It helps the teacher and at the same time gives them a chance for experimentation which is particularly important in cases where the facilities for pupils' experiments are not available.

5

TECHNOLOGY OF TEACHING PHYSICAL SCIENCES

Teaching aids, often known as 'visual' or 'audiovisual' include the episcope, micro-projector, film-strip projector, television, and silent or sound film projector.

Optical Aids

The main types are:

1. for moving pictures, 16 mm sound films, 8 mm silent film loops, television (including closed circuit), and videotapes,
2. for still pictures, 2 in. × 2 in. slides, 35 mm film-strips, overhead film projector, episcope, microprojector, charts and models.

Recent developments and improvements in light sources and optical systems make it possible for these optical aids to be used in day light in a normal classroom or laboratory. Some shading or 'dim out' is often desirable but blackout is not always essential. In this way the use of aids may be integrated into lessons with minimum departure from normal class conditions.

The screen should be so placed in the laboratory or classroom that all pupils have a full and convenient view of it. Generally there are a few good positions but the one chosen, determines to some extent, the type of screen that should be used to obtain the best results.

The screen surface determines the angular distribution of the reflected light. If a high proportion of the incident light is reflected back with little scatter then the angle of satisfactory viewing will be narrow.

Matt white screen surfaces reflect light uniformly in all directions and are suitable in conditions where the audience must be seated in a wide block in front of the screen. They are usually cheap and may even be formed on an area of matt painted wall. Beaded screens reflect a very high proportion of incident light but are directional, that is, most of the light is reflected back within a small angle of about 30°. Such a screen should be used in a long narrow room. Silver screens behave in a way very similar to a beaded screen. Perlux screens are

becoming increasingly popular and give a brilliant picture over a wide viewing angle and make good general purpose screens. The National Council of Educational Research and Training publishes a useful pamphlet giving information about screens, their sizes and the range of mountings.

Projectors

Some film loop projectors, e.g., the technicolour 800E projector, embody a built-in rear projection screen made of translucent material. Such screens have an advantage for while the size is usually limited to that of a large television screen, the projection equipment is located with the screen at the front of the class and the teacher is able to maintain normal contact with the class.

16 mm Sound Film Projectors[1]

A considerable range of 16 mm projectors is available, most incorporating an optical sound system. A few are capable of using magnetic sound tracks and these usually permit recording as well as play, a feature of use to the teacher who makes his own films and wishes to record his own commentary. The speakers may be separate or built into the projector, the latter providing a convenient portable system for use in the classroom. Many projectors incorporate a still picture device enabling a picture to be held on the screen while the teacher discusses points with the class. Another useful facility is the ability to run the film back in order to repeat specially interesting sections.

It is advisable that the persons permitted to use the projector should receive training in its handling and maintenance, regular cleaning being essential for long service and first-class projection. The gate and claw mechanism should be kept free from dust and oil and regular professional servicing is recommended. The projector should always be stopped if there is 'loss of loop' or any other indication of things having gone wrong. Damage to the film can soon be caused by failure to observe the above simple rules and such damage of library copies of films causes the loan charges to be higher than they otherwise would be. Rewinding may be done by hand on a rigidly fixed rewinder, or on the projector. It is advisable to have a number of accessories, such as splicer, spare lamps, and spools, and a simple tool kit will be found useful. If the machine has to be moved about, extra lenses of different focal lengths may be necessary.

Types of Films and their Uses

In considering the uses to which films can be put in science teaching, it is important to remember that it can portray moving phenomena with precision and clarity, that it can show realistically and in detail

1. AMA, AAM, ASE, *Teaching of General Science in Secondary Schools*, John Murray, London.

experiments which cannot normally be demonstrated in the laboratory. It can assemble and correlate illustrations of general principles widely separated in time and space. The film may also be used to show the relationship between scientific studies and their practical appreciations in social and industrial life outside the classroom. Time-lapsed photography enables growth of many crystals, and other slow chemical changes, to be recorded. While fast moving changes and high-speed mechanism may be shown intelligently by high-speed photography. animated drawings provide the science teacher with perfectly drawn and moving diagrammatic illustrations. Modern animation techniques can be used to a great effect for emphasis and exposition, cartoon films being of a particularly valuable application.

The science films have immense potentialities both for scientific research and teaching, particularly in its ability to demonstrate experiments which may be difficult to carry out in schools. The teacher should see and study the film before using it in a class. It should be introduced naturally and without fuss, and not to interrupt the normal tempo of the class. Excellent teaching notes are provided with many science films.

Films as Illustrations

A short film may be introduced into a lesson to illustrate a particular point in much the same way as a lantern slide, book illustration, or chalkboard drawing might be used.

Film Lessons.[2] A film may be used as the basis of a lesson for its use, the teacher should have a detailed knowledge of the content of the film, and should plan the lesson around it. The exact procedure followed may vary with each film and with the teacher's individual methods. Certain general principles should, however, be observed if the maximum value is to be derived from any film lesson.

1. The teacher should spend a proportion of the lesson period in discussing the content of the film, in relating it to the work the class is doing, and in pointing out details worthy of special notice.
2. Carefully chosen oral and written questions should be used to test the pupil's grasp of the content of the film and his observation in detail.

Many teachers conclude the lesson with a second showing of the film. This method ensures that the film is effectively employed as a teaching instrument.

Many films try to cover too much ground; the lesson film should be designed to present a single theme in bold outline with practical illustrations. The main object to be observed in each sequence should

2. AMA, AAM, ASE, op. cit.

always be well in the centre of the photographic frame. The film should be as short as possible, simple and attractively produced in order to awaken youthful curiosity at an early stage.

Some teachers choose to assemble a wide range of material in one short firm. By this means the work of several lessons can be reviewed in a ten or twenty-minute film with economy and efficiency. As does the film lesson, the revision film lesson makes use of discussion and questions, but differences in the proportions of time allotted to these will suggest themselves to the teachers' mind. The revision film should be completely free of extraneous matter, and should make good use of diagrams, and changing viewpoints for emphasis and recapitulation.

Background films: Documentary and general interest films can widen the background of scientific studies either by inclusion in the lesson or by general viewing in the school hall.

Much of the real value in science teaching can be achieved through the presentation of well-balanced and carefully-chosen programmes of documentary films based on industrial and social themes. An extensive range of such films, made under expert supervision by government departments and industrial bodies at home and abroad, is now available, many of them on free loan. The relationship between specialist activities and the general pattern of living, the romance and excitement of scientific achievement, the beauty of natural phenomena revealed by photomicrographic and other techniques, may all be conveyed through these films. The cinema, which uses an idiom readily understood by the youthful mind of today, has considerable dramatic and realistic possibilities. Reasonably employed, these can contribute much to the background and intellectual atmosphere of scientific work.

The Film-Strip and Film Slide Projector

Models are available which are suitable for any school purpose. The largest models, with 750 watt or 1000 watt lamps, are provided with heat filters and cooling fans so that no damage is caused to the filmor to the slide. These instruments are designed to take 35 mm film-strip or 2″×2″ slides. Such material is relatively cheap and is convenient to store and to use. Once threaded, a film-strip can be run through with great ease. The single frame of the standard 35 mm film, viz., 24×18 mm, is the size almost universally adopted.

The Overhead Projector

The overhead projector is a machine which projects an image vertically upwards and then over the shoulder of the operator. Material for projction is placed on a horizontal platform in front of the operator, who can write and draw on the platform while facing his audience. The audience sees an enlarged image of the material on a vertical screen behind and above the operator.

The overhead projector has four special advantages as teaching aids:

1. The operator is facing his audience the whole time while he is using the machine. The rapport between the teacher and the pupils is not lost or interrupted as it often is if the teacher has to turn his back on his students to make use of a chalkboard.
2. Continuous adjustment and alteration of the 'picture' is possible while the projector is in use. This means in practice that a picture can be built up and broken down under the eyes of the students. Lines, colours and notes can be added or removed, and working models can be made to work without interruption in the exposition. Slide projectors and film-strip projectors are inflexible by contrast with the overhead projector.
3. Projection of selected demonstration experiments is possible, so that the whole class can see.
4. Overhead projectors are designed to be used in daylight.

Material for projection is set out on a plastic sheet or on a roll of plastic. Material can be drawn free-hand, traced or produced by some types of duplicating and photocopying machines. The ease with which material for projection can be produced and the wide range of colouring and shading materials available make it possible to produce attractive, and visually exciting teaching material. Once produced the material can be stored and re-used later.

Film Loops

These are films of up to 4½ minutes duration, and are used in projectors such as Technicolour 800 E. Each film is enclosed in a plastic cassette and the two ends are joined to form a continuous loop. The projector can be switched on immediately after the cassette is inserted. No black-out is necessary.

As there is no sound-track, the teacher is able to give a commentary suited to the needs of any particular class. The films can be rerun as often as is necessary and this can be particularly useful for revision work. The most useful feature of this type of film is that it can be shown in the middle of a lesson at the point where it will make the maximum impact. Several such films could be shown if required without any time being wasted, but it is important that the teacher has first made sure that the film starts at the right place. It must be stressed that the 8 mm cassette film can only deal with a very limited topic, and hence its function is different from that of the longer type of 16 mm film.

The Episcope/Epidiascope

The episcope is used to project an image of an opaque object, e.g., a book illustration. Only a small fraction of light falling upon the object (that scattered by the object itself) reaches the screen. The screen image is, therefore, of low intensity and to improve it a high wattage lamp must be used and the room must be sufficiently darkened.

To prevent overheating of the instrument good ventilation is necessary. In some models this is effected by motor-driven fans.

The several good models available are expensive because of large aperture lens required. The instruments are heavy and cumbersome and not convenient for moving from room to room unless mounted on trolleys. In most models the picture is placed on a platform which can be *lowered* by a lever and should be capable of receiving bulky objects such as books. A small episcope is easy to construct if a suitable lens can be obtained. An episcope and a film-strip projector are preferable to the large and heavy epidiascope.

The use of Diagrams, Charts and other Aids

Diagrams and Drawings

The teaching of the proper use of diagrams by pupils presents real difficulty. Many pupils who are good at practical work may give poor and disappointing descriptions of their observations and results. Their note-books do not give a true picture of their manipulative skills, neither are they of any use for revision purposes. These pupils in particular must be taught to realise the importance of accurate and clear drawings, around which so much of the description work may be centred.

A few pupils find it very difficult to draw apparatus at all, while others, with artistic ability, have to be discouraged from making pictures instead of diagrams. Pupils who experience difficulty in drawing the different parts of an apparatus scale must be trained to compare the size and positions of all parts of the apparatus, even if it becomes necessary to measure the different parts.

A pupil might be given further help by asking him to point out the parts of the apparatus represented by particular lines in his drawing. It is especially necessary in the early stages for an apparatus to be shown in the drawing in exactly the same order as it is arranged on the bench, i.e., the sink should be on the right in distillation in both sketch and in the actual apparatus set up by the class. If a pupil cannot make a good drawing even after reasonable training, he should be allowed to omit drawing and describe the apparatus in words. This is rarely necessary, but it emphasises the fact that the drawing is only part of the description.

The Value of Drawings[3]

It is generally agreed that sketches and diagrams are necessary in Physics and Chemistry note-books, because at each stage in the pupil's training they serve a definite purpose. Sketches are very often as important in chemical descriptions as figures are in geometrical proportions.

3. Newbury, N.F., *Teaching of Chemistry in Tropical Secondary Schools*, Oxford University Press.

Large, clear and accurate drawings should be added whenever they make the answer easier to understand.

Pupils must realise quite early that diagrams must always be there for a definite purpose and that they are not always necessary in the description of an experiment. New apparatus should, however, be drawn in the note-books as soon as it has been used. In the preparation of the different gases, for example, it is advisable to show the new arrangement of the different parts of the apparatus.

Pupils should appreciate that scientific drawings are functional and not primarily artistic. The relationship between different parts of the apparatus should be clearly shown, and a pupil should be able to interpret the specific use of the apparatus without difficulty.

Diagrams and Charts for Laboratory Notice Boards

Special advantages result from the use of diagrams, charts and models. A chart forms an essential part of the lesson when the subject-matter is developed around it. It may be built up to summarise several lessons' work, or it may be introduced to bring out some theoretical aspect of Physics and Chemistry or it illustrates an industrial process.

Diagrams and charts are of direct value for reference in class discussions. Diagrams should always be available for the working of steam engine, of water pump, shapes of typical crystals; solubility curves; process of liquefaction of air, extraction and purification of sulphur, fixation of nitrogen, manufacture of sodium carbonate, extraction of metals, and the manufacture of sulphuric acid. Coloured charts of the different indicators and their corresponding colours with different pH values, of flame-tests, borax beads, charcoal-block reduction tests, mass spectra and precipitates in the qualitative group tables, may also be of value when teaching older students.

Posters, advertisements and cuttings from periodicals can often be used to form instructive charts. These should be arranged and pasted on a large sheet to illustrate a special point such as the importance of chemistry in the home, local chemistry, or some special occasion, (e.g., the anniversary of the birth or death of some famous chemist). Pupils should be encouraged to bring illustrations from books and magazines whenever possible.

Charts and Illustrative Material

Science teachers should take advantage of the generosity of manufactures to acquire up-to-date information, by making use of illustrated books, pamphlets, science magazines, charts, illustrations and samples. A greater part of such material is available free. Samples and special exhibits are available on loan from N.C.E.R.T., New Delhi, Ministry of Education and Social Welfare, Government of India, New Delhi and from the embassies of various countries.

With this material the connection of science with the outside world is made evident, a sense of reality is introduced and the utilitarian value of the work done at school can be emphasised.

Models

The contact and lead-chamber processes for making sulphuric acid provide the best examples of manufacturing processes which can be carried out on a small scale. In the lead-chamber process the action of the catalyst nitrogen dioxide may be clearly shown by using stoppered jars containing sulphur dioxide and nitrogen dioxide and repeatedly exposing the resulting mixture of sulphur trioxide and nitric oxide to the oxygen of the air. Laboratory methods to illustrate the commercial preparation of potassium chlorate, sodium bicarbonate, potassium bromide, white lead and chlorine may also be carried out effectively. Although poor yields may be obtained by these laboratory methods, the principles governing the manufacturing processes are made clear.

Other Aids to Physical Sciences Teaching

Besides the popular teaching aids, like charts, models, diagrams, graphic representation, films, film-strips and slides there are some special teaching facilities which are highly essential for the proper development of the science lessons and for the realisation of the major objectives of science teaching. Such aids and facilities having additional pertinence to the teaching of science alone are dealt with here. The science club, science fairs, scientific excursions and hobbies are some among them.

Science Clubs

However, well-thought out a school syllabus may be, and however wide the range of interests catered for, each individual is likely to have his own special enthusiasm. This is true of teachers as well as pupils.

When a few like-minded individuals get together a club may be founded. Numbers are of less importance than sharing of a common interest. The spirit of science is the spirit of discovery. Experience teaches that one of the most exciting and effective ways to impart to the students the joy and adventure of scientific discovery is through science clubs. The club offers the pupil an opportunity for specialisation which he does not have in the classroom. In the club the child choses and picks up scientific work of his taste and enjoys it in a free atmosphere to quench his thirst for his interests, adventure and expressions.

Objectives of Science Club

Given the will and the resources, an ambitious programme for various categories of students can be developed. In fact it can become the nucleus of science teaching and link classroom and laboratory with the community.

(*i*) To learn about science, science careers, and the opportunities, responsibilities, and important role science plays in our democracy.

(*ii*) To explore interest and abilities of the members in relation to the various fields of science.

(*iii*) To cultivate in members the qualities of personality, character, leadership and scientific skills.

(*iv*) To study the lines and influence of great scientists.

Activities for the Science Club

There is no fixed list of activities for science club. As far as possible, these should be based upon the students' interest and aptitudes. A teacher should throw varied ideas off and on. He should not force his ideas and interests on his students. Science club activities are and should remain voluntary.

The following activities are suggested[4]

1. Visual programmes in which lantern slides, 16 mm projectors, film-strip projectors or some other concrete visual aids are employed.
2. *School journeys.* Visits to places of scientific interest such as a power plant, a mill, telephone exchange, weather bureau, city water supply, filtration plant, modern dairy, and museums are always interesting and help to create interest in science.
3. *Work periods.* Some club meetings should be set aside for the members to engage in individual work such as doing experiments, preparing demonstrations, or making posters and exhibits.
4. *Current events.* Some clubs devote one meeting a month to reports and discussions of new developments in science as reported in recent scientific magazines and newspapers.
5. Organising science exhibitions and participation in science fairs.
6. *Special speaker programme.* Science clubs enjoy hearing occasionally, some expert or specialist such as a scientist, an engineer, a forester or a bee-keeper.
7. Science debates and paper reading contents among the club members on various topics of scientific interest.
8. Science question box.
9. Science plays.

Science club activities can be so organised to help the community in various aspects. This is very necessary in Indian conditions. If it can cooperate with the local *Gramsevak*, many demonstrations on health and higiene can be given to the community. In cooperation with the Agricultural Extension Officer and officers in charge of adult

4. Heiss, Obourn and Hoffman, *Modern Science Teaching*, Macmillan Co., New York, 1961.

and social education, the science club can undertake many activities for the improvement of agriculture and for the eradication of many superstitions and false beliefs. The science club can also improvise many apparatuses necessary for the laboratory which otherwise might be very expensive.

Organisation of the Club

School science club should have teacher as a patron, his task being to advise and encourage to approach the headmaster to ask for special facilities, and to supervise correspondence and invitations to visitors.

The students should elect from among their members a chairman, secretary, treasurer and a committee.

The object of the club should be defined, eligibility for membership agreed upon, the number and time of meetings fixed, and the questions of finance and subscriptions decided.

The less the patron is needed to help in organising the club the better. It is for the members to suggest a programme to arrange demonstrations and exhibitions, and to construct models. Visits to objects and places of interest may be planned, a film of particular interest may be shown and discussed from time to time, and outside speakers may be invited to give occasional talks.

Science Fairs and Exhibitions in Schools

Functions like prize distribution, sports week and parents' day are regular annual features of most of the schools. Efforts should be made to hold an annual science fair or exhibition along with any of these.

Science fairs have become so common these days because of their immense importance for developing in the child scientific interests, skills and expression through their displays in the fair. The outcome of science club activities will also be fit for science fairs. The greatest contribution of it lies in the recognition and encouragement that it gives to the student participants.

The objectives of science fairs have been listed as follows:[5]

1. to focus attention on science experiences in school.
2. to stimulate a great interest in science by all pupils.
3. to stimulate a greater interest in scientific investigation over and above the routine class work.
4. to provide stimulation for scientific hobby pursuits.
5. to offer an opportunity for display of scientific talent through exhibits and demonstrations.

5. Jones, Norman R.D., "Science Fairs—Science Education in the Community", *Bulletin of the National Association of Secondary School Principals*, January, 1953.

6. to develop the habit of extra study and provide a useful means of occupying their leisure.

Careful planning is necessary for the success of any science fair. Several committees have to work individually and collectively for its success. If different schools of the same locality collectively organise a science fair it can be made more impressive to the public. Some of the exhibits and experiments suitable for science fairs: Chemical fountains, boiling under reduced pressure, model for preparation of acids, formation of crystals, capillarity, charts, model—both stating and working—experiments and investigations make good exhibits. Working models of pumps, models of solar system, model of Galilean telescope directed to distant objects, experiments in colour; spectrum, colour mixing, models of telegraph, electromagnets, electroplating and electric motors. It is also possible to arrange them in such an order so as to form the natural development for the science course for a particular grade. Several days before the fair, details regarding the exhibits, its nature, space it would need, additional facilities like electricity, water supply etc., have to be called for. There should be a time schedule which should be correctly followed. There should be measures for safety also. The exhibits should be displayed in an artistic manner. The following are some hints for students which may enable them to present an effective display.[6]

1. Be sure to make the display eye-catching and attractive. It should be designed so that it attracts the viewer's attention.
2. Make the display simple. Use an eye-to-follow design which can 'shout out' its message in five to ten seconds. Remember that most viewers will spend only a minute or two with each project, so be sure that they will have an opportunity to understand and appreciate the exhibitors' efforts. Avoid the use of unnecessary decorations of scatter shot arrangements.
3. The lettering should be large and simple. The titles should be short and descriptive and the narrative should be as brief as possible and to the point. It is best to use pictures, drawings and diagrams whenever possible. If the written description is long, it should be placed in a folder like a scientific paper, rather than attempting to place all of it on display.
4. Select colours tastefully. A single shade for background colouring is better than white, which tends to appear vacant. Dark tones should be used to accent the areas which are to be emphasised. Certain colour combinations are more appropriate for some type of projects than others.
5. Effective use of lighting enhances a project. If lights are to be used with the project, care should be taken that no direct light or glare shines into the eyes of the viewer.

6. C.S. Rao (ed.), *Science Teachers' Handbook*, (p. 17), published by American Peace Corps, 1969.

6. The name and the class of the exhibitor should be on the display board.
7. Certain projects may permit the public to operate the controls. Such controls should be sturdy in construction and should prominently display full instructions for their use.

As a sign of encouragement best items should be given prizes. For this judges competent enough should be appointed. The criteria for evaluation may be the scientific approach of the exhibitor, originality, technical skill and workmanship, thoroughness, dramatic value and personal interview with the exhibitor. If organised on a collective basis, shields also may be presented to schools scoring maximum points.

The judging criteria should be made wellknown to the participants in a fair. These criteria may even be displayed for public view.

Scientific Excursions

Scientific excursions refer to visits of the science students to places of scientific interest to gather first-hand information and experiences about the static and dynamic objects and specimens. It is not a mere pleasure trip to a place of interest. But it is an objectives-based short trip undertaken by the students under the guidance of the teacher.

Every science teacher should see that his teaching in the school has a relation to the larger things which are continually taking place outside the school. Visits to factories, museums, zoo and parks, etc., have high educational value. Such visits should form a part of every science course from the point of view of fostering scientific inquiry, for supplementing work in the classroom and laboratory and for the development of the local interest. Places such as a powerhouse, fire-station, soap factory, glass works, iron foundry and botanical gardens never fail to interest children. Some teaching should evidently be given before the visit by way of preparation. The amount of preparation necessary will, of course, depend on the age and technical knowledge of the students. In rural areas visits to farms, orchards and dairies should prove equally interesting.

The places visited will depend not only on locality but also on the subject studied. A class having a course in the study of nature must have opportunities for studying nature at first-hand by means of visits to the country, or to ponds and gardens. A class studying chemistry will find visits to some type of chemical works equally beneficial. Visits to museums, if one is available in the locality should always be encouraged. Museums are generally organised from a simple educational point of view and a single visit is worth many theoretical lessons.

Some of the other places of scientific interest to which such visits can be planned are the telephone exchange, the radio station, botanical

gardens, zoological parks, an airport, a seaport, an observatory, water-works, and industrial exhibitions.

Good previous planning and thorough preparation are quite essential for the success of any excursion. While planning, a number of points are to be considered by the teacher. The strength of the party is an important factor. Below twenty-five will be a handy, convenient number for one teacher. If there are more, more teachers are necessary. After being sure about the number of students, a study of the place to be visited is to be made. A plan as to what is to be observed is to be prepared. The teacher should go to the selected place before hand, locate the probable difficulties likely to be overcome, and make arrangements for meals, stay, etc., for the party. Different committees can be constituted like the transport committee, food arrangement committee, and entertainment committee, etc., to help the teacher. The whole group can be divided into subgroups and put under the charge of a leader. Students should be asked to bring all the equipment necessary for their comfortable stay, for taking notes and for making observations.

During the action phase, when the pupils are on the spot, the teacher should see that all of them are busily changed. Haphazard movements should not be allowed. Everything should be systematic and the pupil should get maximum advantage from the trip. Whenever difficulty arises, it is the responsibility of the teacher to help them by way of offering suggestions and guidance with sympathy. Many qualities like sympathy towards living specimens, appreciation of nature can be developed through natural science projects.

The last phase is the follow-up work. It is here that the excursion is summarised. It may take the form of submitting a report on what they have observed or arranging an exhibition on what they have collected. It is better that different groups of students are put in charge of each item like preserving, mounting, labelling, etc. If necessary a few objective type tests can be administered to students to test if they have understood and grasped things or not.

Scientific Hobbies

A hobby is something which helps in giving an outlet for a child's inquisitiveness and creative faculties.

It cultivates in the child a love for work and a desire to produce something useful and serviceable. It should, therefore, be educative, recreational and profitable if possible.

A hobby is not a regular subject in the curriculum in schools. Special arrangements have to be made to introduce some useful hobbies in educational institutions so that pupils get a chance to develop a taste for recreational work which will widen their interests and outlook.

Now more and more attempts are being made to give a technical bias to our education, a science teacher can make a number of hobbies that bear directly on education in science. Pupils will be found only too enthusiastic, and will not grudge spending time and some money if the science teacher is keen and knows the particular hobbies he is going to start. An attempt should be made to begin with one or two simple and *inexpensive* ones. To start too many hobbies will defeat the purpose, for the teacher will not have the time to give, effectively instructions in all of them. It would be useful if a class-wise list of hobbies is drawn up. In this way pupils will have acquired several hobbies by the time they have reached the highest class in the school. In the higher classes boys may be allowed to specialise in the hobby best suited to their temperaments. A few useful hobbies that may be started as allied activities of the science department are ink making, soap making, oil-refining and making hair-oils, making of face-creams, tooth powder and nail polish, making of phenyle, preparing wood polish, making mosquito cream, blackboard paints and chalk sticks. Photography, preparation of film-strips, slides and working models like that of steam engine, fire and burglar alarm, and electrical devices such as preparation of a working model of simple dynamo, an electric motor can also be included in the list of scientific hobbies for advanced level students of science.

6

PLANNING PHYSICAL SCIENCES INSTRUCTIONS

Good teaching includes the proper selection of content, formulation of objectives, organising activities, based on careful planning. The last factor, namely careful planning is very important for the new entrants in the profession of teaching, which will build confidence in him.

The science teacher has abundance of things which he can use for classroom teaching. Proper selection of the material and the use of various procedures, to be employed in the classroom, necessitate daily lesson planning. Consequently, the daily plan becomes an essential part of classroom teaching.

What is a Lesson Plan ?

The term lesson was interpreted in different ways by different people. Generally, teachers take it as a work to be covered in a class period which runs over 40 minutes or two to three periods.

Others define a lesson as a blueprint—a guide map, a plan or guide for action in the near future; a creative piece of work, a comprehensive chart for classroom teaching, a systematic, elastic approach for the development of concepts, skills and understandings.

Thus in general, lesson plan is a guide for action which will help the teacher in presenting learning experiences.

Uses of Daily Lesson Plans

(*a*) Planning provides direction to the task undertaken. Therefore, a lesson plan gives direction to the teacher and students for teaching and learning;

(*b*) While planning it becomes easier to select proper, adequate subject-matter, needed for particular age group;

(*c*) The subject-matter can be easily organised in a proper and functional way which will help in achieving the instructional objectives of science teaching;

(*d*) Planning gives an idea about the difficulties a teacher may face during the development of the lesson. Therefore, all difficulties

can be anticipated while planning a lesson and their solutions can be incorporated at the planning stage.

(e) Lesson plan develops confidence in the teacher and brings refinement in the art of teaching.

(f) Lesson planning helps the teacher in visualising the needs of the students. Students vary in abilities and interests. An effective teacher attempts to plan for these variations.

Factors Affecting Lesson Planning

1. The nature of school, Urban or Rural.
2. Number of children in the class.
3. Average age of the students.
4. Standard of attainments.
5. Children's knowledge assumed by the teacher.
6. Availability of teaching aids.
7. Aims of the lesson.

Writing the Plans

A teacher needs some information about the class, students and their background before he/she attempts to plan a lesson. Generally a lesson is divided into many stages or steps. When a detail lesson plan is being developed all these steps are used in some form or the other. These steps are:

General Information

(a) Subject; (b) Unit; (c) Lesson/topic; (d) Class; (e) Age of Level of Children; (f) Time; (g) Date.

(See Chapter II for details)

Instructional Objectives as Learning Outcomes

(a) General; (b) Specific.

General: (i) To enable them to live in a scientific world, environment and to draw inferences to solve the related daily problems, to experiment and handle scientific apparatus, (ii) To create interest in science, practical work—about things of daily use and for manual work, (iii) To develop keen observation, reasoning capacity, scientific thinking habit of criticism and judgment, (iv) Development of scientific attitudes, (v) To increase scientific vocabulary and add to the fund of knowledge, (vi) To impart knowledge about the laws of nature, (vii) To introduce pupils to some scientific apparatus, (viii) To acquaint students with scientific inventions, natural objects and their utility.

Specific: Specific objectives should be stated in terms of observable student behaviour. One should not use undefinable terms or statements like (to understand, know, appreciate and familiarise) but one should use measurable terms like the following in stating the objectives of instruction:

to classify, to construct, to calculate, to select, to describe, to order, to write, to distinguish, to design, to synthesize, to apply, to state, to determine, to analyse, and to evaluate.

EXAMPLES 1

Topic : *Dry Cell*

Objective (*Vague*): To make the pupils familiar with the dry cell.

Objective (*Clear*): (*i*) To make the pupils able to construct/analyse a dry cell, (*ii*) To make the pupils able to describe the working of dry cell with chemical equations.

EXAMPLES 2

Topic: *Hard and Soft Water*

Objective (*Vague*): (*i*) To make the students understand Hard and Soft water, (*ii*) To give the students the knowledge of Hard and Soft water.

Objective (*Clear*): (*i*) To make the pupils able to distinguish between soft and hard water, (*ii*) To give the causes for temporary and permanent Hardness of water, (*iii*) To make the hard water soft, (*iv*) To determine experimentally if the water is soft, temporary hard or permanent hard.

These specifications should reflect terminal behaviour of the student and should be written in such specific terms which can be observed and measured. In writing objectives one should provide clarity, appropriateness, adequacy, and attainability.

Previous Knowledge assumed by the Teacher: Development of the lesson is based on the previous knowledge of students. This knowledge reserves as base for further learning. Therefore, relevant assumption by the teacher is a necessity for saving the wastage of time.

Introduction (*of the lesson*): It helps in:

(*a*) Reviewing the previous knowledge of the students.
(*b*) Providing enough opportunity to motivate the students.
(*c*) Introducing the new knowledge. When a new lesson is being introduced, the teacher should try to stimulate and generate pupils interest in the topic. A lesson can be introduced by the help of an effective teaching and/or actual material.

Announcement of the Topic

Instructional Aids: Proper selection and effective use of teaching aids motivate students and clarify the concepts of science. Aids should be used skilfully and at the right time. Their utility depends on proper handling.

Procedure/Method: A variety of methods are used by teachers for teaching. In a lesson plan a brief mention of procedures gives an idea about the approach as well as the activities a teacher will undertake to complete the lesson. While planning a brief lesson plan, procedure can present a vivid picture of the whole lesson.

Development of the Lesson: This comprises all teaching-learning situations which involve:

(*a*) Content, (*b*) Method, (*c*) Active participation of the students.

Content should be selected carefully in terms of the instructional outcomes. It should be accurate, relevant and rich enough in its depth.

In science teaching the following approaches may be used:

1. Demonstration and lecture-cum-illustration.
2. By group introduction and then removing difficulties as they arise.
3. Relating scientific facts to daily life experiences of the students.
4. Questioning techniques.
5. Laboratory and demonstration method.
6. From known to unknown.
7. Posing a problem question.

Make use of concrete things and active participation of pupils in science teaching process. Try to base the lesson on their activities as far as possible.

Application: The true worth of knowledge depend upon its transfer value and the stage of application is meant for enabling the pupils to secure the maximum transfer of acquired knowledge. For this the teacher should think of new situations for the students in which they can apply the learnt knowledge.

Recapitulation/Sectional Recapitulation: The objective at this stage is to help the students to assimilate the lesson by recapitulating it. This stage helps the teacher to know how far the pupils have learnt the lesson, and it also indicates the success with which the lesson was presented. Sectional recapitulation is done after covering every unit of the lesson.

Blackboard Summary: Though the lesson is expected to be learnt in the class, it is necessary for the pupils to have some record of it with them for future reference. The blackboard summary should be brief, precise and logical and it should cover all the important points of the new knowledge presented in the lesson. It may be of written sentences of varying importance, diagrams and tables.

Assignment

The nature of assignment should be such that it admits the scope for creativity and meets the interest of the pupils.

LESSON PLAN

Hydrogen Gas

General Objectives

(*i*) To develop in students scientific thinking and scientific outlook.

(*ii*) To make the students able to use scientific method in science and to correlate the scientific knowledge with the daily life of the students.

(*iii*) To develop in pupils the power of reasoning.

Specific Objectives

(*i*) To make the students able to prepare hydrogen gas in the laboratory.

(*ii*) To make the students able to examine the properties of hydrogen.

(*iii*) To develop the drawing skill of the pupils.

Teaching Aids

Woulf's Bottle, Thistle, Funnel, glass tube, beehive shell, gas jar, glass trough, zinc, sulphuric acid, litmus paper and water. A chart showing the sketch of setted apparatus.

Previous Knowledge

(*i*) The students already know that different gases are formed by the action of different acids on different metals and non-metals.

(*ii*) The students have seen the filling of gas in balloons.

(*iii*) They are also acquainted with symbols, formulae and chemical equations.

Introduction

The teacher will introduce the topic with the help of the following questions:

(*i*) Have you seen the balloon vender filling gas in the balloons?

(*ii*) Why the balloon filled with that gas goes up in the sky? *Gas is lighter than air.*

(*iii*) Can you name the light gases?

Simple Demonstration

The pupil teacher will put zinc pieces into a test tube and add diluted H_2SO_4. He will bring a burning match stick near the mouth of the test tube. There will be an explosion with a sound because of the burning of the gas. This demonstration will motivate the students to know about what has happened. The teacher will explain to students that when diluted H_2SO_4 was poured over the zinc pieces in the test tube, a gas was formed which moved upward, its combustible nature was responsible for explosion. The teacher will now create a problematic situation by asking the students how would you make arrangement in the laboratory to collect it keeping in view its two characteristics:

(*i*) It is lighter than air.

(*ii*) It is combustible.

Announcement of the Topic

Well students, we shall study the laboratory method of preparing hydrogen gas and its important properties.

UNIT I

(*a*) Introducing the apparatus by putting suitable questions.

(*b*) Setting the different components together with the active co-operation of the students.

(*c*) Keeping in view the above two characteristics of the gas, what precautions would you observe while preparing the gas?

Expected Answers (Statement of the Teacher)

(*i*) The cork of the bottle should be air-tight.

(*ii*) The apparatus should be kept away from the burning flame.

(*iii*) The end of the thistle-funnel should remain immersed in the acid.

UNIT II

QUESTIONS

(*i*) Why is gas being collected by the displacement of water?

(*ii*) Mention any property of the gas associated with the above question.

Expected Answers

(*i*) The gas is lighter than air.

(*ii*) The gas is insoluble in water.

The other Properties can be tested as follows:

(*i*) See the gas in the jar and tell its colour. (colourless).

(*ii*) Do you feel any smell? (no).

(*iii*) Shake the gas with water and allow a drop of it to taste. (tasteless).

Statement of the Teacher

The teacher will tell the students that hydrogen (H_2) gas is tasteless, colourless and is lighter than air.

Experiment

Drop a litmus paper (moistened blue and red) into the jar filled with H_2 gas. There is no change in colour.

Statement of the Teacher

The teacher will tell the students that hydrogen gas is neither acidic or alkaline.

Blackboard Summary

A labelled diagram, chemical reaction, precautions and properties will be given.

Chemical reaction

Zinc + Sulphuric Acid = Zinc Sulphate + Hydrogen.

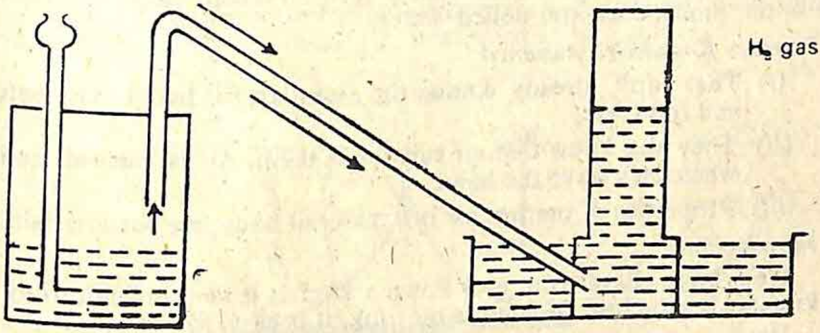
$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

Precautions

(*a*) Apparatus should be air-tight.

(*b*) Apparatus should be kept away from burning flame.

(*c*) The end of the thistle-funnel should remain immersed in the acid.



Lab Preparation of hydrogen gas

$Zn + \text{dil. } H_2SO_4$ Fig. 6.1

Properties

Hydrogen gas is colourless, odourless tasteless, and combustible.
It is lighter than air.
It makes no effect on litmus paper.

Uses

It is used in filling balloons and airships.
It is used in making ammonia.
Reducing agent in laboratory.

Assignment

Prepare hydrogen gas in the laboratory by drawing a neat sketch of the filled apparatus.

Give some of the important properties and uses of hydrogen gas for daily life purposes.

LESSON PLAN NO. 2

Topic: Air Pressure

Objectives

(*i*) To make the pupils clear that air exerts pressure from all sides through simple demonstrations.

(*ii*) To correlate this fact to their life situations and enable them to find its utility to new situations.

(*iii*) To develop in pupils the power of observation and to think independently by creating situations through experimental work.

Teaching Aids

Football bladder, balance, Medberg's hemisphere, gas jar and test tube (Cartesian-diver), Rubber-sheet, thistle-funnel, balloon rubber, Flit-tin, punch-cork and boiled water.

Previous Knowledge Assumed

(*i*) The pupil already knows the essentials for living. Air, water and food, etc.

(*ii*) They also know that air surrounds them. Air is pushed away when they wave the hand.

(*iii*) Properties of matter: air is a material body; air has a weight.

Introduction

Well boys, have you ever flown a kite? It is very difficult to fly a kite if it is too close. If wind is blowing, it is easy. *Why*?

Have you ever peddled the cycle? *Yes*.

Why is it easy to cycle if you move in the direction of the wind, and difficult if you go in the opposite direction?

Put a wooden board on the table in such a position that half of it lies outside the table. Press it, it falls down. Now spread a full sheet of paper on the wooden sheet and again press it, it does not fall down.

Question: Why did it not fall down in the second case?

Answer: Air pressed the sheet of paper from above to down which checked the fall of the wooden sheet.

DEMONSTRATION 1

Student's Activity: Give Medberg's hemisphere made of rubber to a boy in the class and ask him to press them together and then to separate them.

Question: Why is it difficult to separate them?

Answer: Air from the sides is exerting pressure on the hemisphere as shown in Fig. 6.2.

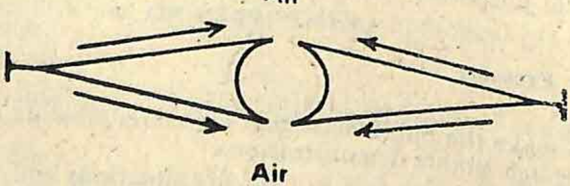


Fig. 6.2

Student's Activity

Ask a student to press a Medberg's hemisphere on the glass plate and then to pick it up.

Question: Why is it difficult to pick up/separate the hemisphere from the glass plate?

Answer: As the air between the hemisphere and glass plate is out, and air from outside is pressing it downward as in Fig. 6.3.

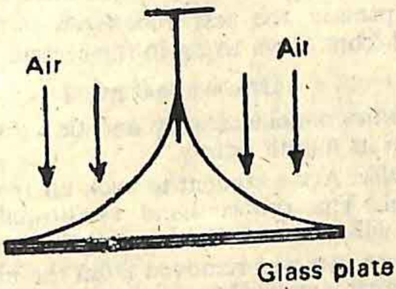


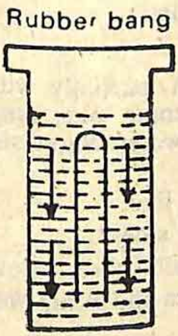
Fig. 6.3

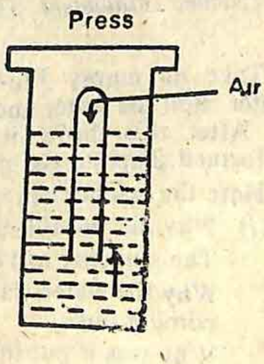
Teacher's Statement

(*i*) Air exerts pressure from above to downward direction.
(*ii*) Air exerts pressure from the sides.

DEMONSTRATION 2

Take a glass cylinder (gas jar type), fill $\frac{3}{4}$ of it with water. Take a test tube and fill it with so much water that when it is inverted in the cylinder full of water, it stands in the inverted balanced position as





Cartesian diver

Fig. 6.4

Fig. 6.5

shown in Figs. 6.4 & 6.5. Bind a stretched rubber band tightly on the mouth of the glass cylinder. Press the rubber band with thumb and fingers, the test tube will go downward because of the pressure of air.

Student's Activity. Ask a student to press the rubber band hard, the test tube will move downward. Release the rubber band, test tube will move upward. It will be quite interesting to students.

Question. Why the test tube moved downward when the rubber band was pressed and upward when it was released?

Answer. Air pressed the test tube from up to down direction in the first case and from down to up in the second case.

DEMONSTRATION 3

(1) Take a thistle-funnel and wrap and tie a rubber band (balloon rubber) on its mouth tightly.

Student's Activity. Ask a student to suck air from the open end of the thistle-funnel. The rubber band swallowed inside the thistle-funnel. Students will be encouraged to tell the reasons.

Expected Answer. Air was removed from the interior of the funnel and air from outside exerted pressure on the rubber band causing it to swallow.

Blow air from the open-end side of the thistle-funnel. The rubber band is swallowed outside. (See Fig. 6.6)

Fig. 6.6

Teacher's statement. The air exerts pressure from sides.

DEMONSTRATION 4

Take an empty Flit-tin in good condition, fill it partially with water. Boil the water and when the steam begins to come out, cork it. After this throw it in a basket containing cold water. Show the deformed shape to the students.

Here the teacher can create a problematic situation like:

(*i*) Why did the Flit-tin box get deformed from all sides?

The students will explain this on the basis of their observation.

Why the water was boiled and then corked when the steam was coming out?

Why was it put in cold water?

What happened during these two steps?

The air pressed the tin box from all sides as the pressure inside the box was reduced when it was thrown in the cold water.

Statement of the Teacher. Air exerts pressure from all sides, from upward to downward and from downward to upward.

Correlation of the Lesson with Daily Life

(*i*) Why do you press the rubber tube of the pen in order to fill up the pen?

(*ii*) Why don't we get deformed when air is pressing us from all sides?

(*iii*) Why an enclosure made of kite-paper containing burning earthen lamp go up in the sky?

Application to Daily Life of the Pupils

(*i*) Sucking water or soda-water through a straw tube.

(*ii*) Placing a hollow key to the lip when air is sucked out of it.

(*iii*) Rise of water in syringe.

(*iv*) Eye-dropper.

Recapitulation

(*i*) Why do lizards not fall?

(*ii*) How does an elephant drink water through its trunk?

(*iii*) Why do we not feel the considerable pressure of air?

(*iv*) Fill up an empty glass gas jar (with round corners) with water in excess. Slide a wet cover glass over its mouth to cover it. Invert the jar, the cover glass (lid) does not fall. Why?

7

THE PRACTICAL WORK IN PHYSICAL SCIENCES

Improvisation in Physical Sciences

The science teacher generally complains of lack of equipment for the dullness of his lessons, and allows his pupils to dull monotony of note-taking and passive learning of the text-book. A good science teacher, however, finds in the same circumstances a challenge to his ingenuity. With a resourceful mind he adapts his lessons to the scientific material available. There is always the great 'out of doors'; the winds and the clouds, the stars, the rainbows, the changing seasons, lightning clouds and twinkling stars to be watched and noticed.

Should there be no magnesium or phosphorus to exhibit vividly a particular example of oxidation, there are always available on the small scale nails and screws, and on the large scale massive iron objects. And though the oxidation of magnesium and phosphorus may be more swift and exciting, the oxidation of iron is vastly more important.

The list of substitutes for the common laboratory equipment is as long as the teacher is expected to be ingenious. With patience, simplified versions of more complicated apparatus can be made. In fact the simpler the apparatus the better is the pupil able to appreciate the methods used and the facts to be illustrated. The refinements required in order to obtain very accurate results belong to apparatus more suited to the needs of advanced students. Such apparatus is often complex, and making the various corrections, which its proper use usually demands, can be a source of more confusion that help to the beginner. Some emergency or simply the need for economy, can develop the ability to construct apparatus that would otherwise be bought. This gives practice in improvising original devices, and results in a class being confronted with equipment which may be crude but of which the function is clear. Such contingencies, far from being a disaster, provide benefits of great value to both teacher and students.

For a rain gauge there may be no cylindrical brass case, with a brass funnel and a measuring cylinder exactly graduated to suit the apparatus.

Yet it may be noted that in at least one works for the extraction of salt from sea-water by evaporation, the nights rainfall is measured simply by noting the depth of water in an empty canned fruit tin left upright in an exposed place. No better apparatus exists for teaching what, precisely, is meant by a 'rainfall of one inch'.

Diagrams intended to show how certain devices work are often difficult to follow. It is far better if the pupil can handle the device itself, and take it to pieces. It would be unreasonable in most instances to treat new instruments in this way, but old, discarded pieces of apparatus can readily be used for the purpose. Such pieces of apparatus, thrown out because no longer serviceable, can often be found in junk heaps, in garages, in cycle-repair shops, in radio-repair shops, in electric supply stations and in electrical contractors' sheds. All sorts of useful oddments are thrown away by builders, and by maintenance men working on engineering and electrical projects. All these can be 'dissected to destruction', or used lavishly. A friendly contractor can save a science laboratory a great deal of money at no cost to himself. To make such acquaintances is one of the tasks that lie within the science teacher's proper duty; to acquaint his class with the source of his booty, is the teacher's reasonable return to the donor.

Suggestions for the construction of simple apparatus, equipment and models, may often be found in good text-books and magazines. A school club for model-making can render the science department great service.

Notes on Some Possible Improvisations[1]

Accumulators, lead: Car batteries are of this type. Old accumulators can be obtained from garages. They can be cut through with a hack-saw to show the construction of the plates, the wooden separators, etc.

Secondary Storage Cells, e.g., lead accumulators, or nickel-iron ('Nife') accumulators, supply direct current (D.C.). These are suitable for all purposes, and if single cells are available, the current may be used for either torch bulbs or car lamps. 'Nife' accumulators are better than lead accumulators for school use. The fluid they contain is caustic alkali (not sulphuric acid), they are lighter to carry, and they will withstand harsher treatment without disintegration of the plates.

Accumulators need to be charged from time to time. If mains A.C. is available, an apparatus for charging accumulators should be fixed to a wall, preferably in a preparation room. Such chargers, which are also rectifiers and so provide direct current, are supplied complete with ammeter and resistances for measuring and regulating the rate of charging. With the aid of such a battery-charger and reasonable care, a collection of accumulators can be kept in working order for years.

1. Saunders, H.N., *The Teaching of General Science in Tropical Secondary Schools*, Oxford University Press, pp. 227-28.

Very inexpensive 'trickle chargers' are also obtainable. These provide a much smaller current, so the charging process takes longer. But they are efficient and fool-proof. Accumulators should never be charged at a rate higher than that recommended by the manufacturers. At this rate they cannot be spoiled if left on charge for too long. All that happens when they are fully charged, i.e., when the chemical changes in the plates are complete, is that the liquid (acid or alkali) is electrolysed, yielding oxygen and hydrogen. Thus addition of distilled water replaces any loss.

Laboratory Solutions

Accumulator Solutions[2]

(*a*) **Lead Accumulator**: The specific gravity of the sulphuric acid in various conditions of the battery is as follows:

State of battery	*Specific gravity*
Fully charged......	1.28
Half charged......	1.21
Discharged......	1.15

The above figures are approximate. The recommendations of the makers, usually printed on the battery, should be followed. A rough guide to the making of a solution of sulphuric acid of specific gravity 1.28 is as follows:

Concentrated sulphuric acid is added slowly, with stirring to a beaker two-thirds full of distilled water, until solution is almost boiling. The solution is allowed to cool, and more acid is added, with similar precautions, until the solution is again almost boiling. After cooling to room temperature, the specific gravity is adjusted by the addition of more acid or more water, according to the hydrometer reading.

(*b*) **Nickel-iron (Nife) Accumulator**: The specific gravity of the caustic soda solution is as follows:

Specific gravity when the battery is	*Temperature* 60°C	80°C	100°C
(*a*) first filled	1.190	1.185	1.180
(*b*) working and fully charged	1.170	1.165	1.160

4 lb (2 kg) of caustic soda are dissolved in 1 gallon (5 litres) of water to provide a solution of the approximate strength required. It can then be diluted with water as necessary.

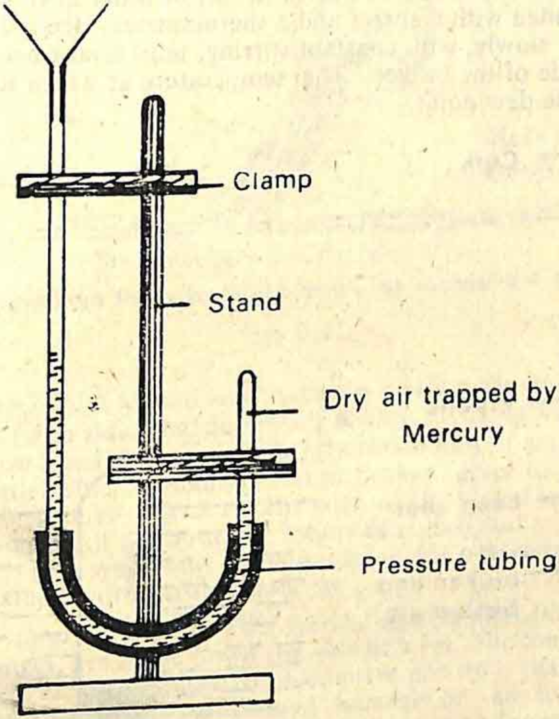
Calorimeters Large: Empty 2 lb. canned fruit tins can be used.

Small: Empty 1 lb. canned fruit tins, or cigarette or tobacco tins, can be used. If quantitative measurements are being made, it should be remembered that 'tin' is mainly iron covered with a very thin layer of tin. The specific heat of the 'tin' can be taken as 0.11 calories per gram.

2. op. cit., pp. 265-66.

Clips, Spring (for rectangular mirrors): A wooden rectangular block, with a saw-cut vertically down one face, will usually hold plane mirrors satisfactorily. Two such blocks are better, and can also be used for spherical mirrors and lenses. Clothes pegs of the spring type also make satisfactory mirrors and lens holders.

Boyle's Law Apparatus: A glass tube J can be replaced by two tubes, the shorter one sealed at one end, joined by rubber pressure-tubing.



Boyl's law apparatus

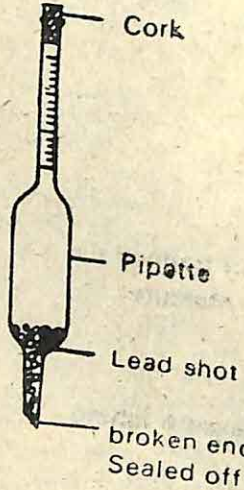
Fig. 7.1

These can be set up in the appropriate J-shape on a stand. It is easier to get the right amount of air into the short tube when both tubes can at first be made to lean, independently, in any direction (see Fig. 7.1).

Hare's Apparatus: This can be set up using straight glass tubing and a glass or metal 1-piece, with rubber-tubing connections. It can be fastened to a wooden stand by brass saddles, or the long tubes may be held in two separate burette clamps fixed on one stand.

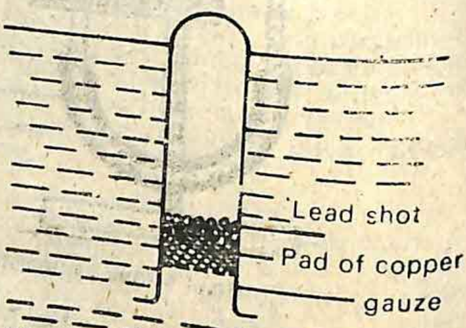
Hydrometers: These can be made from broken pipettes. The broken tube is sealed off just below the bulb, and a suitable amount of small lead shot is inserted (Fig. 7.2). The end of the tube is closed with a rubber, or cork, stopper. (A suitable stopper is often left in the borer when a hole is made through a cork). The stem is calibrated with thin rings of white paint or quick drying enamel, or marked with grease pencil.

Hydrometer (Dew-point Apparatus): To find the approximate value of the dew-point, a beaker one-third full of water at room temperature, is provided with a stirrer and a thermometer. Ice-cold water is added very slowly, with constant stirring, until a mist begins to form on the outside of the beaker. The temperature at which the mist first appears is the dew-point.



A hydrometer
(made from broken
pipette)

Fig. 7.2



(An improvised Cartesian Diver)

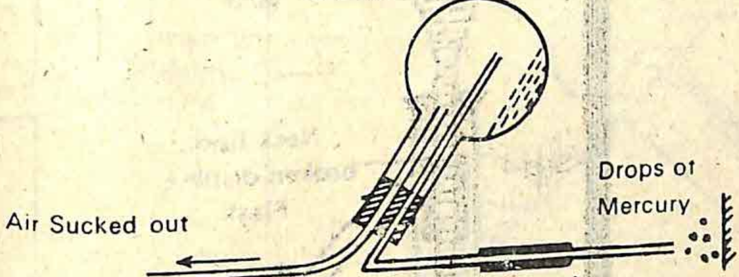
Fig. 7.3

Diver, Cartesian: A small test-tube has a piece of copper gauze plugged into the open end. Lead shot are placed in the test-tube a few at a time, until it will almost sink when placed in an inverted position in a glass cylinder of water (see Fig. 7.3).

Mercury. Air bubbles appear in a tube which is being filled with mercury. To remove them the tube is closed with the finger, before it

is quite full, and inverted to allow a large air bubble to travel up. When the tube is turned up again the large bubble reverses its track, collecting the smaller ones as it moves upwards and escapes. The small amount of mercury needed to fill the tube is then added.

Mercury split on tray, bench or floor, may be recorded by sucking it into a small 'washbottle' (see Fig. 7.4).



(The recovery of Split Mercury)
Air is withdrawn from the Wash-bottle by means of a filter pump.

Fig. 7.4

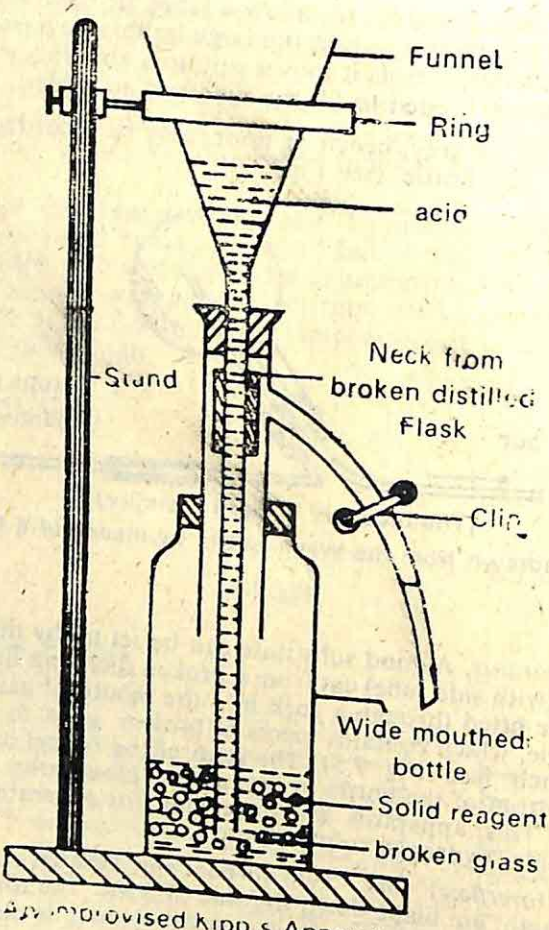
Kipp's Apparatus. A good substitute can be set up by the making use of the neck (with side tube) cut from a broken distilling flask. This and a funnel are fitted through a cork into the mouth of gas jar or wide-necked bottle, which contains pieces of broken glass to a depth of about an inch (see Fig. 7.5). The stem of the funnel is extended to reach the bottom of the bottle by means of a glass tube with rubber connection. This apparatus is convenient for generating hydrogen, carbon dioxide, hydrogen sulphate, etc.

'*Eureka*' (*overflow*) *Can*. Two vertical and parallel cuts, of exactly the same length, are made down the side of a tin. The tongue of metal thus formed is bent outwards. A concave groove is made along the tongue by tapping with a ball-headed hammer or an iron rod (see Fig. 7.6). The object, the volume of which is to be found, is inserted slowly, so that all the displaced liquid flows down the groove into the receiving vessel.

Filter Paper. There are times when it is useful to remember that a sheet of white blotting paper can be used in place of filter paper.

Fuse Holders, Porcelain. These can usually be found in the junk heap of a contractor for electrical installations.

Resistances, Electric, Variabie (*Rheostats*). A discarded volume control switch of this type can often be obtained from the junk in a wireless repair shop. It can be mounted on a piece of wood or ebonite. A resistance of this kind provides a useful control for electrolysis experiments.



(Improvised Kipp's Apparatus)
Fig. 7.5

Test-tube holders. A piece of paper, folded into a strip of four to eight thicknesses, is an adequate substitute when wrapped round the tube (Fig. 7.7).

Care, Maintenance and use of some Common Apparatus

Ammeters and Voltmeters. The moving-coil type is the common one in the school laboratory and on the instrument panel of an automobile, and is suitable for use on any direct current (D.C.) supply of electricity. But industrial and household supplies are usually of alternating current (A.C.), for the measurement of which ammeters must be of the moving-iron, or the hot-wire, type. The same applies to Voltmeters.

Instruments with a zero-centred scale are often preferable to those graduated from zero upwards, because it is not always easy to decide

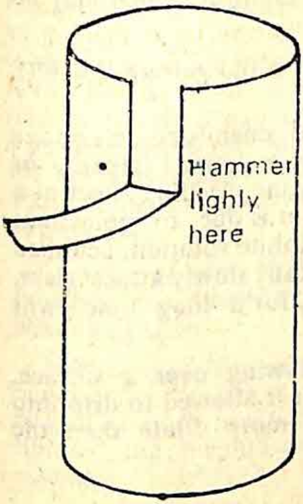


Fig. 7.6

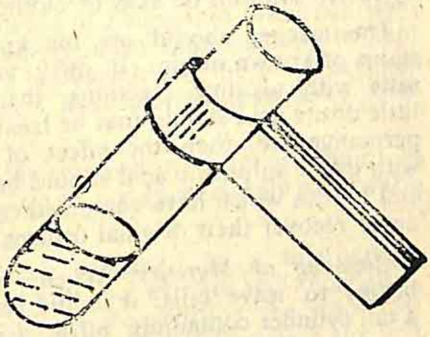


Fig. 7.7

upon the direction of the current in a circuit. This does not matter in the case of a zero-centre instrument, and there is no need to change the terminal connections. Table 7.1 gives further information.

Table 7.1

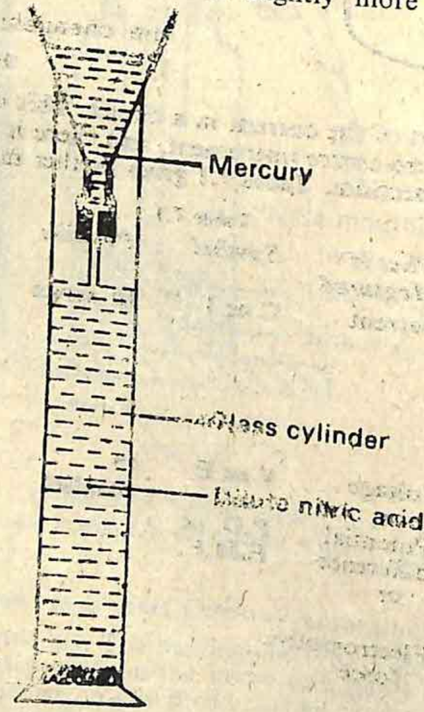
Instrument	*What is Measured*	*Symbol*	*Position*	*Assumption*
Ammeter	Current	C or I	In series	The instrument has no resistance, leaving the total resistance of the circuit unaltered.
Voltmeter	Voltage or Potential difference or Electromotive force	V or E or P.D. or E.M.F.	In parallel	The instrument offers infinite resistance, taking none of the total current in the circuit.
				In general, the better the quality of the instrument the more clearly are these assumptions correct.

3. *Cleaning of Glassware.* 100 g. of potassium dichromate are dissolved in a solution of 100 g. concentrated sulphuric acid in 1 litre of water. Glassware can be soaked in the solution, which may be used over and over again.

Caution. Great care should be taken to avoid getting this very corrosive solution on skin or clothes.

The teacher should use his knowledge of chemistry to remove stains of known origin. If dirty vessels have contained alkalis, or salts with alkaline reactions, then obviously the cleaning effect of a little dilute acid should first be tried; if the stain is due to potassium permanganate, then the effect of sodium sulphite solution, acidified with dilute sulphuric acid should be tried. Alkalis slowly attack glass, and bottles which have contained caustic soda, for a long time, will never recover their original transparency.

Cleaning of Mercury. When mercury, flowing over a surface, begins to leave 'tails,' it should be cleaned. It is allowed to drip into a tall cylinder containing nitric acid slightly more dilute than the



The cleaning of Mercury

Fig. 7.8

usual bench reagent. If the mercury falls through the acid in a fine stream, as it does when made to pass through a capillary tube attached to the end of a funnel, so much the better (see Fig. 7.8). The mercury is then shaken up with water in a strong bottle to wash it free from acid. Finally it is allowed to pass through a pinhole made in the middle of a filter paper, which is folded in a funnel in the usual way. The last drops of mercury remaining in the funnel should be kept for the next occasion when mercury is cleaned. The mercury may be warmed in an air oven before the final filtering, if required particularly dry.

Cleaning of paint brushes. After the removal of as much paint as possible, the brushes should be washed out immediately with warm water and soap.

Microscopes. Young pupils are often fascinated by a microscope, but usually benefit very little from its use, as time and experience, as well as much practice in technique, are required for the appreciation of the magnification. Frequent use of hand lenses is the first essential.

Only the patient skill of the expert can bring much profit from the use of high-powered microscope, and to provide one is usually misguided enthusiasm on the part of a teacher of General Science. Suitable slides are seldom made by amateurs, for the sections are generally too thick and thus appear opaque. Instead of such a costly instrument, an objective of 1-inch focal length with eyepiece (X 1/6) is recommended. This allows inspection of the whole area beneath a cover slip, makes illumination comparatively easy, means that adjustment of focus is not critical, and permits movement of the slide by hand with enough control to retain the object in the field of view. The magnification is quite sufficient to show the main features of insects, the shape and surface of the smallest seeds, typical specimens of pollen, and characteristic crystal formations. The rule is: use the least magnification which will serve the particular purpose.

A teacher should try to train his pupils in correct microscope technique as soon as they begin to use the instrument, however, low its power be. The objective is marked $\frac{1}{4}$ inch or $\frac{1}{2}$ inch or 1 inch, for example, to show the distance between lens and object when the latter is in focus. The instrument should always be arranged so that the distance is less than this, and then, as the observer views the slide, the adjusting screw should be turned so that the objective is racked away from the slide. Risk of damage to the lens is eliminated by following this procedure, as the objective cannot then be pressed down on the slide. Pupils should also be taught to keep both eyes open, so that they can learn to observe with one while using the other to draw a sketch of the image. For this reason the microscope should be placed so that the eyepiece is about 12 inches above bench level.

Rubber. Petrol, vaseline and other petroleum products cause rubber tubing and corks to perish rapidly. Thus it is unwise to use vaseline as a lubricant for slipping rubber tubing on to glass tubing. Special rubber lubricant may be purchased and if this is not available saliva may be used. Car break fluid also serves the purpose.

Rubber and rubber articles should be kept well dusted with French chalk, in a box or drawer, to prevent rapid deterioration in hot climates. Strangely enough, it may also be stored in kerosene vapour, as long as precautions are taken to keep it clear of the liquid. This may be done by placing a shallow dish of kerosene on the bottom of a small cupboard, with close-fitting door, and putting the rubber on perforated shelves.

Galvanometers: These will only carry a very small current, usually about one-hundredth of an ampere. They are generally used with a high resistance in series, or a low resistance in parallel (a shunt). If the instrument is used to determine the moment when no current is passing in a circuit (e.g., with Wheatstone's bridges, 'Post Office' boxes, etc.), it should at first be protected by connecting a piece of copper wire across the terminals. The null point is found approximately. The copper wire is then removed and the full sensitivity of the instrument allowed to come into play.

Pupils should not be permitted to use one of these sensitive instruments without the wire shunt until the teacher has checked the circuit and given permission for it to be removed.

Soldering fluxes: The following are suitable:

Tallow for joining lead to lead, or brass to lead; rosin or 'killed spirits' for joints in brass, copper, tinplate, zinc; 'killed spirits' for iron and silver.

After soldering, 'killed spirits' should be washed off with water, and rosin or fluxite, with methylated spirit. ('killed spirits' consist of concentrated hydrochloric acid to which zinc was added until there was no further reaction.)

Stirrup for suspending a magnet. In order to ensure that the magnet will hang horizontally, two equal loops are made in a piece of thread, and then knotted together near the top ends of the loops. The spare ends are cut off, leaving a long thread to suspend the loops.

Stoppers. The removal of a stopper which is stuck in the neck of a bottle is a task the science teacher often has to undertake. The following methods are suggested, in progressive order of severity. If the bottle contains solids which are not dangerous, the method can be applied while the bottle is over a bench; if it contains liquid, it should be held in or over a sink. The methods are not always successful, and bottles occasionally break and spill their contents.

(*a*) The stopper is tapped gently all around its side with the wooden handle of any available tool, or with a small, hard piece of wood.

If the stopper overlaps the neck, it may be struck slightly upwards each time. (*b*) The bottle is inverted with stopper and neck immersed in almost boiling water for 15 to 20 seconds. It is then removed and the stopper immediately tapped as in (*a*). (*c*) (Not to be used with bottles containing inflammable or dangerous liquids or solids.) The bottle is held at an angle, and rotated so that a candle flame deposits a layer of soot all around the neck. Method (*a*) is applied after a few moments. (*b*) If the stopper still refuses to loosen, it may be necces-sary to cut off the neck of the bottle. To do this a series of the marks are made around the neck with a sharp triangular file. The end of a piece of glass rod, or drawn-out tubing is heated strongly in a flame and applied, while hot, to a file mark. A few attempts will usually cause a slight crack to start. The process is then repeated at the next file mark, or the first crack is encouraged to travel around the neck by movement of the hot point of the glass along the crack in the desired direction. The neck is given a sharp knock with a piece of wood as in (*a*).

Thermometers. If these are left for some time in a rubber cork, they are often difficult to remove. A cork bore, or a size such that the thermometer passes through it, is used to rebore the cork, while the thermometer remains inside the bore. The thermometer then comes out with a thin ring of rubber which may be scrapped off.

Tropical conditions. There are many causes of trouble in a labo-ratory, especially during a wet season in the tropics. Materials perish, papers stick together, instruments rust, specimens go mouldy, lenses develop a fungus which quickly renders them useless and ruins their accurately ground surfaces. In addition, ants, termites and other insects continue their endless work of destruction.

Whatever can be kept in an air-tight container should be so kept. Glass jars, such as specimen jars with lids well greased, are ideal. Screw-capped bottles, e.g., those which have contained sweets, are very useful. Metal containers, such as biscuit tins, etc., can be render-ed fairly air-tight by strapping the joint between the lid and container with insulating tape.

Lenses of microscopes should be kept in a desiccator when not in use. Needles can be inserted in a piece of material in which some vaseline has been rubbed. Metal instruments such as screw gauges, vernier callipers, tuning forks, etc., should be greased. The screws of retort stand bosses, rings and clamps should be oiled frequently. Scalpels should be smeared with vaseline and kept in a case. The metal parts of tools should be rubbed over with an oily rag.

Paste, gum and glue should contain some chemicals to make them repellant to insects. Such adhesives are sold specially prepared for the tropics. But if the teacher makes his own, the addition of a very

small quantity of a solution of mercuric chloride, during the preparation, is generally effective.

Biological specimens seem to be the favourite food of some species of minute ants. Dusting with D.D.T. deters the ants but spoils the look of the specimens. If mounted insects are left unprotected, these almost invisible ants eat out the intestines and the specimens disintegrate.

8

EVALUATION IN TEACHING PHYSICAL SCIENCES

Examination and Evaluation

The term 'examination' is too common to need any explanations. It comes as a source of fear to all the students, and no system of education is abso utely free from it. "Examinations are formidable even to the best prepared, for the greatest fool may ask more than the wisest man can answer." In India the whole system of education is very much under the clutches of examinations. All educationists have condemned it, but no one could suggest a suitable alternative for it. The examinations simply assess the standards attained by the students in different academic subjects. Evaluation is more than examining the students in different academic subjects.

"It is studying and assessing achievement and growth in relation to the potential of the student and the objectives of the study."[2] It is a continuous and cumulative process and is a function of both the teacher and the taught and is interlinked with teaching-objectives and learning experiences. This inter-relationship of the three aspects of teaching-learning situation is represented in a triangular form.

In teaching Physical Sciences, science teachers first determine what they will teach—Science content. They are next concerned with how they will teach—Teaching Methods and processes. Finally they need to know how well they taught and how well children learnt—Evaluation.

In other words, evaluation means judging the effectiveness of teaching-learning processes. It will include techniques of assessing pupil's progress in acquiring both science content, skills in scientific process, and other behavioural changes as a result of learning physical sciences. It also includes self-assessment on the part of the teacher by assessing the effectiveness of formation of objectives, and providing

1. C.C. Coltan. quoted from the *Indian Express*, 13 June, 1970, p. 6.
2. Miller & Blaydes, *Methods and Materials for Teaching the Biological Sciences*, Ch. II, p. 12, McGraw-Hill, 1962.

learning experiences[3] in teaching-learning process.

Characteristics of Evaluation

Evaluation is continuous and cumulative in nature. It is not merely a device to be used at the end of a particular period fixed for science instructions, say, yearly, half-yearly, fortnightly or even at the end of a science lesson, instead, evaluation goes on minute by minute throughout each lesson. This can be achieved by careful questioning and observation on the part of the teacher. All this should be properly recorded in the student cumulative record.

Evaluation is Diagnostic. It helps the teachers in identifying a child's science strength, weaknesses, and interests. It will teach him by disclosing to him his strength and weakness, by indicating clearly his degree of process, by showing him where emphasis needs to be placed, by training him in ways of obtaining more knowledge and by giving him practice in its application to life situations.

The Evaluation Process

What is to be evaluated? Evaluation is closely related to the teacher's goals (objectives in terms of behavioural changes) learning experiences provided in realising these goals and devising suitable assessment procedures. Indeed it is evaluation that provides a measure of progress towards the realisation of the objectives of teaching and the effectiveness of learning experiences provided for this purpose.

The objectives of teaching Physical Sciences have already been discussed, and the major objectives are stated:

1. The pupil acquires knowledge of facts, concepts, principles and processes in sciences;
2. The pupil develops understanding of facts, concepts and principles;
3. The pupil applies scientific knowledge in a new or unfamiliar situation;
4. The pupil develops skill in drawing diagrams, manipulating apparatus, preserving specimens, improvisation, observations and scientific expressions.
5. The pupil develops interest in the world of science;
6. The pupil develops scientific attitudes, values and qualities of head and heart;
7. The pupil develops a sense of appreciation of scientific phenomena and achievements.

Evaluation includes to measure to what extent the above objectives are realised and thus help remedial teaching by enriching learning experiences.

3. *Learning experiences*: It is an interaction between the teacher, learner and the content. The learning experiences can be brought about through a number of ways such as library, text-books, experiments, radio, films, science clubs, field-trips, projects, museums or other similar learning situations.

How to Evaluate a Student of Physical Sciences

All evidences that reveal that some objectives have been realised can be used as means for evaluation. Richardson classifies them as follows:[4]

(a) *What students do.* Anecdotal records of significant observable behaviour, original laboratory developments, voluntary contribution to science resources (specimens, finding scientific literature and activities), instances of laboratory resourcefulness.

(b) *What students say.* Class discussions, conferences, informal conversations, oral reports and panel discussions.

(c) *What students write.* Laboratory reports and note-books, reports of readings. Field-trips, tests and examinations.

(d) *What students produce.* Laboratory products and apparatus set-ups, improvisations, displays, collections, photographs. Results of individual project-work, production of and or participation in scientific skits and plays.

(e) *What students read.* Depth of reading in relation to assignments, voluntary readings of books and magazines in scientific and related fields, newspaper reports of current, scientific and technological developments.

Evaluation Tools

The main useful and important tools which are commonly used for evaluating Physical Sciences are given below:

1. *Evaluation by paper and pencil devices*
   (a) Verbal tests, either "objective" or essay type in form.
   (b) Diagrams, sketches, pictures, charts and models.
   (c) Rating scales and checklists.

2. *Analysis of work products*: According to acceptable criteria (apparatus set-ups, improvised apparatus, note-books, students collections; and reports of the committees).

3. *Classroom questioning and discussion.*

4. *Observation of significant behaviour.*
   (a) Informal as in day-by-day classroom or laboratory activities, or
   (b) Systematic, in arranged situation to know specific type of behaviour.

5. Conferences and interviews with individuals or with groups.

Types of Tests

Tests in science can be broadly classified under three heads:

1. Performance tests,

4. John S. Richardson, *Science Teaching in Secondary Schools*, Ch. 7, p. 132.

2. Picture and Diagram tests, and
3. Verbal tests.

Verbal tests are of two types: (*a*) Oral, and (*b*) Written

The written type tests can further be classified: (*a*) Essay sype, (*b*) Short description/Explanation type, (*c*) Short-answer type/Objective type tests.

I. *Performance Tests*

These tests measure pupil's manipulative skill and laboratory techniques for performing experiments. In these tests the students are provided with necessary equipments and are asked to set up the apparatus for the laboratory preparation of different gases like hydrogen, oxygen and carbondioxide, etc., handling of burette and use of indicators for arriving at the exact end-point and noting the readings from the burette. Students' performance may also be observed to find out the skills while making connections so that an electric bell may ring, making the connections so that an induction coil may work and setting up working models.

II. *Picture and Diagram Tests*

As we know pictures, diagrams and sketches are quite useful for the teaching of Physical Sciences. Pupils are also asked to draw diagrams, pictures and sketches to explain Physics and Chemistry topics. Sometimes they are given pictures, diagrams and sketches relating to many topics with accompanying questions.

Pupil's pictures and diagrams show their power of observation and depth of understanding.

The following points should be taken into consideration while making an assessment of a diagram:

(*a*) Does it represent an apparatus which serve the purpose?
(*b*) Are the different parts shown in right proportion?
(*c*) Is it neatly and clearly drawn?
(*d*) Is it accurately labelled?

The following are examples of this type of test:

(*a*) Draw a diagram of the working of an air-pump and label its different parts.
(*b*) Draw and label a diagram showing the laboratory preparation of hydrogen gas.

Sometimes the pupils are provided with incorrect/incomplete diagrams, they are asked to make them correct/complete.

Pupils may also be provided with pictures and diagrams to label correctly.

The following are examples:

(*a*) In the laboratory preparation of carbondioxide, a diagram may be given as the gas being collected by the downward

displacement of air. The pupils may be asked to correct the diagram.

(*b*) In the laboratory preparation of hydrogen gas, a diagram may be given showing the collection of hydrogen gas by the downward displacement of water. The pupils may be asked to label the different parts.

(*c*) The diagram of an electric bulb, a key and dry cell may be provided and the students may be asked to make connections so that the bulb gives light when the circuit is completed.

III. *Verbal Tests*

Verbal tests can be classified under two broad categories, oral and written. These tests measure the factual knowledge that the pupils have acquired. The pupils should be told beforehand the nature of the test items, instructions to respond so as to get the best results. Subject-matter which has not been discussed in the classroom should not be tested. The main drawback with these tests is as under:[5]

(*a*) A teacher may not express precisely what he wishes to find out from the pupil,

(*b*) The pupil may not interpret the question correctly,

(*c*) The pupil may not express his knowledge accurately,

(*d*) Finally, the teacher may misinterpret the pupil's answer.

1. *Oral Tests*. Generally oral tests take the form of interviews. In such tests, the examiners ask questions, the answer of which the students have to give orally. Oral tests are more flexible than other types for the examiner can build upon the answers of the pupils. The pupils also get a chance to explain their answers further and clarify points to the examiner. There is provision for immediate reinforcement by way of correcting the answers then and there. In these tests the examiners are liberated from the menace of marking answer-books. Oral tests cover much more syllabi than other form of tests.

The teacher should plan thoroughly and carefully for a successful oral tests. He should be fully aware of the objectives of each question put in the test. Questions should be framed in simple, clear and unambiguous language. They should be thought-provoking and must not be either too simple or too difficult for the students to answer. Pupils should be given time to think before they are called upon to answer. The examiners are also required to establish rapport with the pupils before oral testing.

2. *Written Tests*

(*i*) *The Essay Type*. The written type of tests are popular of all other types of tests because of their ease in administration. Essay type tests are one of them. Essay type questions ask the students to write

5. Thurber and Collette, *Teaching Science in Today's Secondary Schools*, Ch. II, p. 282.

out long answers to one question. This gives the pupils training in self-expression, use of proper words, organising subject-matter, arguing logically and explaining a scientific process with proper attention to the sequence of operations involved. Essay type tests can be of two types. It may be a single question like 'Discuss the Newton's Laws of Motion', or a group of short questions like 'Define Newton's First Law of Motion', state the 'Third Law of Motion', and 'If an individual is standing in a moving train, the train stops suddenly, in which direction the individual falls?'

The essay type questions have many advantages. They are highly flexible. Many factors like the knowlegde in recent and remote facts, useful knowledge for the present and future—power of description and observation and graphic representation and the ability to arrange arguments to lead, to generalisation and to apply knowledge to new situations.

The main disadvantage of essay type tests is in its subjectivity of scoring. As answers vary widely, when assessed by different examiners or sometimes when assessed by the same examiner on different occasions, the same pupil gets different marks. Essay questions give more emphasis for factual information and thus directly are responsible for cramming.

The modern trend is to discard the essay type and substitute in its place short answers and objective type tests. But the total discard of essay type is not proper because certain areas can be tested only by them.

(*ii*) *The Short Explanation Type Tests*: As essay type questions require long answers, these questions require very short answers, generally one or two sentences but never more than a short paragraph. Definitions, short explanations, citing reasons can be asked as short-answer questions. These questions prove more useful if only one skill is tested by one question.

Examples

(*i*) Define Potential Energy?

(*ii*) Define an Acid/Base?

(*iii*) What is oxidation?

(*iv*) Why is it difficult to walk on slippery roads?

Though these tests are not perfectly objective they can be scored more objectively than essay type tests.

(3) *The Objective Type Tests*: The following are the advantages of the objective-type test items.

1. Because the items are short, it is possible to include a greater number of items than would be possible in essay type of testings. A large number of items give adequate coverage of the content and add to the reliability of the test.
2. Marking of objective tests is much more rapid than that of an

essay type test. Objective type tests can be either machine-marked or hand-marked even by a layman.

3. Each item in an objective test can be pre-tested before it is used in the test so that ambiguities in the wording can be discovered. It is also possible thus to confirm that each item in the test is of the correct level of difficulty and contributes positively to what the test as a whole is valuating.

Kinds of Objective Type Test Items

A. *Logical Selection Type*

These exercises require the pupil cross out the name of an object which, not resembling the other, does not fit into the same category. The usual instruction to pupils is:

Cross out, in the following list, the word which does not seem to belong to the same group as the other.

Examples

(*a*) Wavelength, frequency, compression, amplitude: All are connected with 'Wave Motion' and can be measured in some units, except 'compression' which merely records a condition and is to be crossed out.

(*b*) Pints, litres, grams, cubic-centimeters. In this all are measurements of volume, except 'grams' which is a measure of weight and is to be crossed out.

These tests enable the teacher to know the pupils' ability to analyse a problem and suggest to themselves various hypotheses until, having hit upon a probable one, they eliminate the item which the hypothesis would exclude. Consider the following example in which a student is required to cross out one word from the following:

Water, mercury, chalk, common salt.

A pupil might begin by asking himself 'Is there one solid while the rest are liquid?—No, there are two solids, chalk and common salt. Then: Is one used for food while the others not?—No, for both water and common salt are part of a normal diet. 'Is only one white?—No, chalk and salt are both white. So he goes on, until he notices that mercury is an element, while the rest are compounds, and proceeds to cross it out. He might also cross it out on the grounds that it is the only metal, or the only good conductor of an electric current.

B. *Multiple-Choice Type*

The test provides a choice of several possible answers, of which only one is correct. The usual instructions to pupils is: 'Put a tick mark in the box against the correct answer to each of the following questions.

EXAMPLES

(*a*) The speed of sound in air is:

(*i*) 10 ft per second ( )
(*ii*) 550 ft per second ( )
(*iii*) 1 mile in 5 seconds ( )
(*iv*) 60 miles per hour ( )

(*b*) The weight of a body is reduced at the moon due to reduction in:

(*i*) Density of the body ( )
(*ii*) Mass of the body ( )
(*iii*) Gravity of the body ( )
(*iv*) Specific gravity of the body ( )

(*c*) A rocket works on the principle of:

(*i*) Conservation of mass ( )
(*ii*) Conservation of energy ( )
(*iii*) Conservation of linear momentum ( )
(*iv*) Conservation of angular momentum ( )

(*d*) A Klinostat is used:

(*i*) To show the effect of gravity on the growth of plants ( )
(*ii*) To measure the distance between successive waves ( )
(*iii*) To measure the angle between a slope and the horizontal ( )
(*iv*) To regulate the temperature of an oven ( )

C. *Sense Discrimination Type*

A somewhat more complicated version of the second type of test (*B*) requires a pupil to select those words and phrases which will combine to form a logical or correct statement.

The instructions to pupils is: 'Cross out words or phrases from each group so that a logical or correct statement remains.'

EXAMPLES

(*a*) Acid turns $\left\{\begin{array}{l}\text{red}\\ \text{blue}\end{array}\right\}$ litmus $\left\{\begin{array}{l}\text{red}\\ \text{blue}\end{array}\right.$

(*b*) When steam reacts with $\left\{\begin{array}{l}\text{copper}\\ \text{magnesium}\\ \text{silver}\end{array}\right.$ $\left.\begin{array}{l}\text{hydrogen}\\ \text{oxygen}\\ \text{nitrogen}\end{array}\right\}$ is liberated

(*c*) When an object $\left\{\begin{array}{l}\text{floats}\\ \text{sinks}\end{array}\right\}$ in water the $\left\{\begin{array}{l}\text{upward thrust}\\ \text{downward thrust}\end{array}\right\}$

is $\left\{\begin{array}{l}\text{less than}\\ \text{equal to}\\ \text{more than}\end{array}\right\}$ the weight of the object.

The sentences left should read: (*a*) acids turn blue litmus red, (*b*) when steam reacts with magnesium, hydrogen is liberated, (*c*) there are two alternatives—either, when an object floats in water the upward thrust is equal to the weight of the object, or, when an object sinks in water the upward thrust is less than the weight of the object.

D. *Matching Type*

The test requires appropriate words in one column to be matched against corresponding words in another column.

The instruction to pupils is: Put in front of the letters in the second column, the number of corresponding word (or name, phrase, or formula, etc.) in the first column.

EXAMPLES

(*a*)	(*i*) Na_2CO_3	( )	(1) Copper sulphate
	(*ii*) $NaHCO_3$	( )	(2) Manganese dioxide
	(*iii*) $MgCl_2$	( )	(3) Sodium carbonate
	(*iv*) KNo_3	( )	(4) Magnesium chloride
	(*v*) $CuSo_4$	( )	(5) Sodium bicarbonate
	(*vi*) MnO_2	( )	(6) Potassium nitrate
(*b*)	(*i*) ohm	( )	(1) Current
	(*ii*) volt	( )	(2) Resistance
	(*iii*) ampere	( )	(3) Power
	(*iv*) watt	( )	(4) Potential difference

The correct order of the numbers to be placed in the second column (*a*) v, vi, i, iii, ii, iv and (*b*) iii, i, iv, ii

E. *Reasoning Type*

The test suggests a variety of possible answers to a question. Of these the pupil is asked to select that which is the most logical. The usual instruction to pupil is: Put a tick mark in the bracket against the answer which seems to you to be the most reasonable.

EXAMPLES

(*a*) A thick vessel of ordinary glass may crack if you pour boiling water into it because:

(*i*) thick glass is not strong, ( )
(*ii*) the careless use of hot water can cause accidents, ( )
(*iii*) the thick glass expands unevenly, ( )
(*iv*) water is a poor conductor of heat. ( )

(*b*) An observer only sees a rainbow when he stands with his back turned towards the sun because:

(i) The sun is always shining brightly when a rainbow is seen, ( )
(ii) It is made of many colours, ( )
(iii) There is always rain in the neighbourhood of a rainbow, ( )
(iv) It is formed by light reflected from distant rain drops. ( )

(c) Ammonia gas is not collected over water because:
(i) It is alkaline gas ( )
(ii) It is colourless ( )
(iii) It dissolves readily in water ( )
(iv) It is lighter than air ( )

The answers to be ticked are: (*a*) iii; (*b*) iv; (*c*) iii.

F. *Completion Type*

This type of test enables a teacher to evaluate a great deal of factual knowledge without much writing by the pupil, who has to fill in blanks left in sentences or lists, etc. The instruction to pupils is simply: "Fill in the blanks in the following".

EXAMPLES

(*a*) To every action there is equal and opposite......
(*b*) Hydrogen gas is collected by the displacement of......
(*c*) The pitch of a note given out by a stretched wire can be raised if the wire is......
(*d*) If three cells of 1.5 volts are connected in parallel, their combined voltage will be......

G. *True/False Type*

The pupil is required to say whether the scientific statement is true or false. The usual instruction to pupil is: "Against each of the following statements, put, in the space provided, a "T" if the statement is true, or an "F" if the statement is false."

EXAMPLES

(*a*) Carbon dioxide supports combustion ( )
(*b*) Moist air is heavier than dry air ( )
(*c*) Coconut oil is denser than water ( )
(*d*) It is necessary to have a medium (for transfer of heat by radiation) ( )

H. *Numerical Tests*

Tests can be designed to give a quick review of physical facts, in so far as these provide data for simple calculations. In such tests the arithmetic required should be reduced to a minimum, for it is the knowledge, and the ability to apply; physical laws which are the real subjects of investigation.

EXAMPLES

1. Six volts applied to an electric circuit gave current of 2 amperes. What was the resistance of the circuit?
2. Express 55°C in °F.
3. If a sample of gas occupies 100 cc at 27°C, how many cc will it occupy at 127°C at the same temperature?
4. If two resistances, each of 3 ohms are connected in parallel, their combined resistance is......

IV. *Evaluating General Progress*

(*a*) *A test of the essay type.*

My favourite subject
What Science Text book I like best, and why?
Wonders of Science?

(*b*) *The atmosphere of a class may be considered.*

Do the pupils come to class willingly or reluctantly?
At the end of a lesson are they satisfied and happy?
Do they seek to be excused from attending classes?

(*c*) If the organization of the school permits, the help of pupils may be enlisted in preparing for lessons by setting out experiments, in keeping shelves and cupboards tidy, in renewing labels, and in keeping the scientific apparatus clean and in good condition. A teacher can make a fair estimate of a pupil's attitude to the subject, and of the extent to which he has developed a sense of responsibility, by observing his willingness to take in turn his duties and his appearance in the laboratory at the appointed time.

9

ORGANIZING A SCIENCE CURRICULUM

The selection of the content usually comes from a particular syllabus which has been developed by a state government, department of education or a local board of education. Unfortunately, most science teachers are not directly involved in the construction and organization of a complete science curriculum. Hence, it is recommended that whenever possible, the classroom science teacher plays a vital role in the development and organization of the science programme he is expected to follow.

Criteria for organizing Science content

1. Science teachers meet regularly with science specialists, with consultants, and with science teachers from other schools to plan and formulate objectives.

The possible danger is that a science curriculum which is organized by others cannot be accepted with as much enthusiasm and understanding as when the science teacher is an active participant. The natural curiosity of students is considered throughout the sequence of learning activities. To stimulate this curiosity in the high school, the teacher prepares demonstrations from time to time with no discussion or formal introduction on his part. For example, a titration demonstration is set up in which drops of a standard acid solution are added to a base. Within a few seconds or minutes students note a change in solution colour. This approach not only fosters pupil curiosity but can also lead to problem solving or other creative activities on the part of the learners.

2. Science teachers organize materials in order to develop scientific attitudes, skills in scientific discovery through an emphasis on inductive and deductive reasoning, and open-ended experimental activities which include attitudes and manipulative skills as well as scientific information (cognitive domain).

The science teacher, for example, displays four bottles containing clear liquids. They all look like water but the students are given an opportunity to identify the problem how to figure out which bottle contains pure water. A series of hypotheses and experiments are proposed, with observations and an analysis which leads to the

ultimate solution of the problem. Students learn scientific attitudes of suspended judgement and not to draw hasty conclusions in addition to laboratory skills of designing experiments to test hypotheses.

3. The science curriculum is organized to include up-to-date references, resource materials, and resource persons from community, and allows the needed flexibility to bring in contemporary discoveries.

Values and appreciations are influenced by selected readings from history, biography, and philosophy of science. In many communities a mechanical engineer, biochemist, local health officer and other scientific personnel can make worthy contributions to strengthen the science programme. Publications such as Science Today, Science Reporter, Science Digest, and Science Newsletter should be used in organizing a science curriculum. Books dealing with the philosophy of science, the history of science, and the lives of great scientists, and the science magazines should be both in the library and the classroom.

4. Pupil-teacher planning and preplanning can be a very strong influence in the improvement of curriculum organization.

A science teacher learns much about science and the students when pupils participate with the teacher in curriculum planning. Individual students as well as groups of students propose and suggest projects in science that are used for the school museum or science fair. Individual students perform demonstrations in which they have shown interest in bringing to the attention of the class. Textbooks and other reading assignments are related to some of the interests and abilities of the students, not just the prescribed readings by the science teacher.

5. The organization of a science curriculum should enable teachers to substitute new ideas for out-dated ones and to augment and supplement current scientific information. Flexibility becomes the factor for maintaining an up-to-date science programme.

Approaches to organizing Content

Logical and Psychological Approach: The science teacher is always faced with the problem of organizing the content and learning activities which have been selected to develop and obtain the objectives. Some science text-books begin the unit in chemistry with the nature of matter because the author believes this is a logical approach to the introduction of science. Some science teachers believe this is the best way to organize a beginning science course. For example, if a student is not given a basic understanding of the nature of matter, it becomes difficult to teach subsequent concepts pertaining to energy, chemical changes, and more advanced ideas.

In physics and chemistry classes, it is common to observe that the nature of matter and energy usually is introduced at the beginning

of the year through a series of definitions. Other topics used to introduce a science course are air, water, how the scientists work, the human machine, and others.

Psychological principles of learning such as readiness, re-enforcement, applications of scientific principles, transfer, functional relationships, and associations with pupil experiences and interests should be considered carefully in the logical organization of a science curriculum.

Simple-to-Complex versus Known-to-Unknown Approach

Many science text-books and syllabi are organized by beginning with simple ideas or structures. For example, force is the simplest unit of structure in Physical Sciences, hence many physical sciences teachers organize a course with this concept as the introduction. After this laws of motion and then the simple machines are introduced.

The teacher can usually justify his organization of science content through rationalization. The principle underlying the organization of science experiences for students is that effective learning is developed through the use of sound principles of psychology rather than through rationalization. Some of these principles of learning developed through research are: scientific information should be meaningful and significant. learning materials should be related possibly to pupil experiences, audio-visual aids should be used for more effective learning; the need for motivation should arise from within the learner, for maximum achievement in science, pupils' social and emotional needs must be taken into account by the teachers.

Contemporary and Functional Approach

Explorations in space usually are reported on the front page of most daily newspapers. Reports of research in atomic energy, plastics, and space journeys frequently appear as headlines. The significance of these contemporary scientific discoveries is their impact on man in modern society. Therefore, it is conceivable that some schools will organize the science programmes around scientific events and their effects upon people. The functional approach may include problem-solving activities and open-ended experiments to stress creative activities in science.

The organization and selection of science materials for instructional purposes will vary from teacher to teacher, class to class, and school to school. In physical sciences classes, a teacher may prefer to begin with atomic energy rather than mechanics. Within a given topic or unit, some teachers may begin by referring to a newspaper item pertaining to atomic blasts or radio-active fall-out as a basin for stimulating learning in this unit. Another teacher may prefer to initiate learning by performing a demonstration such as the detection of radioactive materials through the use of a Geiger Counter.

A different approach would be to begin with a stimulating motion picture film on atomic energy followed by a lively discussion. It is

typical to find that many teachers, in a traditional manner, use a model of a given atom as a basis for developing the several concepts about atomic energy. A few teachers may use previous pupil readings and experiences such as visits to industrial plants to initiate learning.

Basic criteria to be used in selecting and organizing science materials for effective instruction include: significant contemporary issues and discoveries in science; pupil needs and interests; the degree of emphasis on specific objectives such as behavioural changes, attitudes and knowledge; the type of resources available in the community and the nation; the background and experience of the science teacher; the ability to keep abreast of scientific discoveries; and the kind of initiative and resourcefulness employed by the science teacher.

Topic and Principle Approach

A good number of syllabi list science topics and, for each topic, many basic principles or concepts. In some handbooks for teachers the principles may be stated as understandings or concepts. Facts appear under each concept or understanding. The need for synthesizing scientific facts that show relationships and applications is apparent. Demonstrations, individual pupil experiments in the laboratory, projects, reading assignments, and other learning activities are usually suggested in order that the students develop, rather than memorize, the major scientific principle or understanding.

Spiral Curriculum

As an illustration of how concepts can be extended from one grade level to another for re-enforcement and the development of deeper meanings, the following concepts on magnetism are listed.

Lower Grades

1. Magnets pick up different things.
2. Magnets pick up, push or pull things made of iron and steel.
3. Magnets help us in the home and other places.
4. Magnets have different shapes and sizes.
5. Magnets lose much of their energy when they are dropped, pounded or heated.
6. Magnets can pull through water, glass, paper, and other objects.

Upper Grades

1 Magnets have two poles, North and South.
2. The earth is a large magnet and also has two poles.
3. A compass needle can be made with a bar magnet.
4. A compass needle is a magent like poles repel and unlike.
5. Like poles repel and, unlike, attract each other.
6. Generally a compass needle tends to point toward magnetic north.

7. Permanent magnets are made from cobalt, nickel and iron.
8. Iron filings can help to make a magnetic field visible.
9. Magnets are important in navigation and industry.

Junior High School

1. Magnetism is a form of energy.
2. Compass errors may be due to electromagnetic disturbances.
3. The angle of declination (magnetic variation) of a compass varies with the magnetic field surrounding it.
4. Electricity is induced in a coil when a magent is moved back and forth through a coil of wire.
5. Electromagnets receive current pulsations and help to produce sound in telephones.
6. The magnetic force between two poles depend on their strength and distance from each other.
7. Magnetic intensity may be measured in Guass units.
8. The degree to which molecules are aligned in a linear order determines the strength of a magnet.
9. Arbitrary right and left hand rules describe electric currents and magnetic fields.

Senior High School Physics

1. The number of turns or loops in a coil of wire and current intensity affect the strength of an electromagnet.
2. The motion of electrons around atomic nuclei is related to the propagation of minute magnetic fields in molecules.
3. Most electrical motors are operated by pulsating magnetic fields.
4. Coulomb's Law:

$$F = \frac{mm^1}{d^2} \text{ dynes}$$

Another illustration of how concepts became more complex as they are developed from lower grades through high school is the study of atoms and atomic energy. In the lower grades through high school is the study of atoms and atomic energy. In the lower grades students learn, "Matter is made up of small particles called molecules" and i, the upper grades, "All matter contains atoms that are made up of pron tons, electrons, and neutrons." In Junior High School the concept "Electrons move from one atom to another during chemical change" is an extension from others started or developed in the elementary school. On the Senior High School", the production of alphabeta, and gamma rays during radioactive disintegration," can be explained.

"Discovery is not to see something first but to establish solid connections between the previously known and the hitherto unknown that

constitutes the essence of scientific discovery."[1]

Robert Wickware says, "a modern programme of science for children cannot be concerned only with a body of content of ideas, but it must help them acquire understanding of how these very ideas have developed and will continue to be modified as new techniques and related data became available."[2]

1. Sclye, Hans, *The Stress of Life*, New York, McGraw-Hill Book Co., Inc., 1956, p. 6.
2. Wickware, Robert, K., Science Teaching and Creativity, *Educational Leadership*, 10: 159-67, Dec. 1952.

10

INNOVATIONS IN PHYSICAL SCIENCES

A. Inquiry and Discussions

Courses in Physics and Chemistry that originally were taught for rote memorization were changed to problems and methods of discovery in the learning process. Laboratory work became open-ended, with many opportunities for deductive and inductive thinking. Answers to an experiment could not be found by merely looking them up in the textbook. Students had to perform and discover the processes in arriving at a solution or understanding of the problem or physical or chemical concept. Development of cause and effect relationships that emphasize investigations provide students with the basis for inferring conclusions based on evidence. Mathematics skills are used in developing theoretical concepts in chemistry and physics courses.

Demonstrations, experiments, pupils research, and project should lead to the development of understandings or generalizations in a physics class. The developmental or inquiry approach should be emphasized whenever possible. Students should be able to differentiate between an observation and an interpretation. However, the physics teacher needs to develop suitable demonstrations and laboratory experiences to enable students to make the required observations along with evaluations. The machanical role learning of physics principles should be de-emphasized.

The problem having been identified and stated, the teacher asks pupils for their ideas (hypotheses). The teacher elicits a few hypotheses, as, for example, use a pulley, a crowbar, or an inclined plane. A brief discussion may occur at this point since it is important for students to learn how to suggest and screen hypotheses. The next step should encourage pupils to test each of these hypotheses by designing experiments. The process of experimentation enables the students to reject, modify, or accept a hypothesis. The self-rejection or self-acceptance of a hypothesis appears to be more effective for greater retention and learning.

A significant part of the problem-solving approach is the evaluation of experiments. The observations made during the experiments and the evaluation of data in a critical fashion constitute a major step before the students are able to formulate a generalization or a conclusion.

B. Programmed Instruction or Teaching Machines

Programmed instruction was developed as a means of individualizing instruction. Most activities are programmed by printing sheets with inserts or answer-type paragraphs that enable the learner to continue at his own speed and to check whether he can continue by noting whether his response is correct. A few types of the programmed materials are actual machines that are either push-button controlled or paper or cardboard controlled by the learner. Some resemble toys and have an excellent initial appeal.

Teaching machines are excellent supplements to instruction because they make students active rather than passive participants in learning as in the case of other audio-visual aids like TV, radio, movies, and slides. The learner must respond consecutively to a good number of questions, and feedback is furnished on whether his responses are correct. Some of the machines have levers and knobs, mistakes are recorded, and students may be admonished as they proceed in using the self (or auto instructional) device. Many of the machines are printed textbooks or programmed texts.

The following comprise features of a complete teaching system:

1. Programme, whether linear or branching type, prepared with due care for content, objectives, and for the machines structure, constructed not necessarily by the teacher, but by a qualified person, and revised on the basis of one or more trials.

2. Storage, the information and questions of the programme. The sheer paper bulk of this material whether in the form of programmed textbooks, discs or roller foldover sheets suggests that microfilm will prove to be more convenient.

3. Display or presentation to the learner whether by programmed book, mechanical or electronic apparatus, recordings, or simulator, or combination of these.

4. Response by the learner of some objective or observable sort. In this respect, a teaching machine system differs radically from that of the motion picture or televison. The response sought, whether recognition, recall, or performance, depends on the objectives of instruction.

5. Pacing, preferably by the learner but sometimes properly regulated by the machine on the basis of the learner's competence or the timing demands of the product.

6. Comparator, the arrangement by which the response is compared with the correct one given either by the programme or automatically.

7. Feedback, or knowledge of results or reinforcement, the means by which the appropriateness of the response is communicated to the learner either as information or reward.

8. Collator-recorder, the collection and recording of learner processes, whether right or wrong, number and type of errors, etc., with a

view either to improving the programme or the learner's responses. This is done by school personnel, mechanically, or electronically.

9. Selector, used with multiple responses, particularly with branching programme in the form of directions to the learner as to what part of the programme to turn to following his choice of responses.

10. Computer, with almost unlimited potential for satisfying all the above requirements except preparing the programmes.[1]

Skinner maintains: "The machine itself, of course, does not teach."[2] It acts like a private tutor in re enforcing learning by the student through an orderly and sequential arrangement of responses, giving clues where needed to prompt correct responses. This is an attempt to individualize instruction by having students proceed at their own rate of learning through a mass approach media.

C. Team Teaching in Science –The Lecture Plus

The use of several teachers to form a team is another recent innovation for secondary schools. Team teaching as a practice has been functioning in a good number of colleges and universities for many years. In this generally a team of three or more faculty specialists are invited. Each specialist presents a series of lectures from his speciality to a large group of students (perhaps 75 to a few hundred in a lecture hall). The large group is broken down to many smaller sections for discussion, quiz, and laboratory. Team teaching in science should be not only lectures but should include laboratory, discussion, research, and related procedures that stress inquiry.

D. Personalised System of Instructions

New Approach to Teaching—PSI

This teaching method –Personalized System of Instruction—PSI, *Keller Plan* or *Self-paced study* is associated with the name of F.S. Keller who with J.C. Sharma, R. Azzi and C.M. Bori devised it in 1963 to meet the needs of a new psychological programme.

Def. of PSI

The Personalised System of Instruction is defined as the method in which each student is served as an individual by another person, face to face and one to one. In spite of the fact that the class may consist of 100 students, the PSI teacher expects almost all his students to learn their material well and is prepared to award high grades to those who do, regardless of their relative standing in the class. He accepts the

1. Skinner, B.F., Teaching Machines, Science, 128: 969-997, Oct. 1958.
2. Stolurow, Hawrence. M., Teaching by Machine, U.S. Office of Education, Cooperative Research Monograph, No. 6, 196!, p. 61.

responsibility. He accepts the responsibility of meeting his goal within the normal limits of manpower, space and equipment.

Assumptions of PSI

PSI has been developed on the basis of the following assumptions:

1. No two individuals are alike. Every person is a complete individual of his own pattern.

2. Many individual differences affect a student progress in instruction.

3. If instructional presentations vary in response to individual differences, all learners can achieve the same terminal performance.

Organisation of a PSI Course

In this method the PSI teacher divides his course into small units of work, writes a "Study guide" for each unit to supplement the textbook and recruits a corps of the proctors who are willing to participate for academic credit. He meets the class and explains how the course runs.

Instructions to the PSI Pupils

1. Each student will work individually at his own pace.
2. Each student must pass unit of the course before going on to the next one.
3. Lectures and other instructional content will be provided occasionally only for environmental purposes.
4. Essential subject will be given in writing, on tape or film, by computer or by any other means to the student when he is ready.
5. Each student will have a proctor who evaluates his work immediately, face to face and also provides personal tutoring, counselling and encouragement. With slight variation in classroom management, a PSI format will fit into the traditional organization of our educational system because:

(*a*) The PSI format utilizes conventional classroom facilities and does not require special learning centres or elaborate physical facilities.

(*b*) The Keller Plan adapts to the traditional course time limit which is usually six hours in schools and three or four hours at the university level in our country.

(*c*) The personalised work relies on traditional textbooks and materials except study guide which is prepared by the PSI teacher. A study guide is the nucleus of the course.

Main PSI Personnel

Four major individuals are necessary for efficient operations (1) The PSI teacher, (2) PSI Instructor, (3) Proctor, (4) Class assistant.

The Role of the PSI Teacher

The success of PSI programme depends upon the competency of PSI teacher. He is the leader of this course. He plays a vital role for better output of this operation. His roles are:

1. He works as a manager and an observer
2. He deals with the situations which go beyond the control of PSI Instructor and the Proctor.
3. He solves the problems of a student who missed the course for two weeks.
4. Special problems of handicapped students are tackled by him.
5. The deficiencies of his prepared materials for PSI course are removed by him.
6. He maintains motivation and interest among the pupils.
7. He arranges all necessary materials and incentive for prompt work.
8. He is responsible for creating cordial and cooperative relations among the personnel. For this he praises the good work of his students and his staff.
9. He brings about democratic environment and avoids threats and punishments.
10. He pays keen attention to the consequences that follow his students' behaviour.
11. He distributes good written materials like study guide and test forms, etc.

Role of the PSI Instructor

1. To design the course instructions.
2. To help PSI teacher in preparing competent written materials.
3. To set up adequate book keeping practices.
4. To cope with the inevitable day-to-day decisions regarding classroom policies.
5. To arbitrate any disagreement that may arise between a student and a proctor.

The Proctor

The proctor has the most important aspect of the PSI classroom. It is through his efforts and availability that the course is 'personalised'. In most PSI courses, a ratio of one proctor for every ten students has proved to be effective. He is a helper to the instructor. The selection of the proctors can be done externally and internally. Externally the proctors are selected who are graduate students and internally proctors

are appointed from the PSI students who have proved their masery of the most course units by a particular test day. Internal procttors correct and discuss tests of their classmates who have not progressed so far in the course materials.

Class Assistants

Class assistants are also necessary to run PSI course well. They are responsible for unit test, check out and for other helps. One or two assistants over the class with less than 100 students are essential for smooth functioning.

Salient Features of PSI

The success of Keller Plan depends upon the following steps which are necessary and essential features of PSI. These are:

1. Outcome specifications.
2. Small units of work.
3. Immediate and specific feedback at every step.
4. A requirement of mastery at every step.
5. Self pacing.
6. Interaction with PSI personnel.
7. Absence of regular lectures.
8. Successive approximation.
9. Active responding.
10. Critical information written by PSI teacher about the learner.
11. *Use of Proctors and Instructors*

PSI seems to work well because it involves small units of work, immediate and specific feedback at every step and a requirement of mastery at every step. Other features seem to be less crucial.

For whom is PSI Effective?

An important concern in PSI research is the student for whom the method is most effective.

The PSI course is most beneficial for the low aptitude students. High aptitude students would do almost as well as through any other methods. It also appears to depend on the course and on the materials and procedures that PSI personnel use. When the content to be mastered is complex and difficult the high aptitude students may be helped more by small steps, feedback and mastery. With less demanding material the low achievers may get the extra boost from PSI methodology.

E. Supplement Classroom Instructors

Books and other Publications

Uses of a Science Textbook. In most, the textbook serves as a guide

to the syllabus or becomes the syllabus. Under such conditions the textbook practically suggests—what should be taught. In each case, however, the science teacher is encouraged to supplement the material from the test or other required assignments by introducing reading assignments from other books, paperbacks, periodicals, reprints, and newspapers. The intent of each of the curriculum committee was to use not only their own materials but also to stimulate reading from other books and publications.

Another function of the textbook is to supplement or enrich the science syllabus. Frequently, science teachers may use more than one kind of science text for a given class. They may wish to have their students read more than one text for a specific assignment.

Science textbooks that supplement instruction are usually employed by teachers as references or encyclopedic volumes to encourage students to look up additional information beyond that covered in the classroom activity. The text used primarily as a reference is frequently employed by the student to look up specific information that may not have been understood in class. The book should have clear explanations, good illustrations, appropriate vocabulary, and a good writing style. Specific explanations and applications should accompany delineation of scientific principles in this type of text.

A textbook should help *pre-enforce learning* that may have originated in the classroom or laboratory, on the field trip or outside of school. Such re-enforcement should come from self-study and homework as well as from independent reading from supplementary books and periodicals. One of the misuses of a textbook is to require students to read on assignment because the science teacher did not have sufficient time to cover it in class. Home-work from a textbook is used to drill or to give students practice in retaining information and being able to apply it in different situations or in solving problems. This process of reinforcing learning by reading again or by repetition of seeing or hearing experiences will become part of the pupil learning experience if it has meaning or purpose.

Adopting a Science Textbook

Most science departments/State governments have a faculty committee who decide which book is to be adopted. In small high school, the science teacher usually makes the decision. Does he decide on the basis that it appeals to him or that the book is most readable for the students? Does he consider the functions of a science textbook and how he intends to use it in class? What are the student reactions to the textbook?

These are a few questions the science teacher takes into consideration before adopting a classroom textbook. He should also evaluate the criteria to be used in selecting a text. Printed materials, especially textbooks, make a vital contribution to the teaching of science.

Despite the charges that textbooks are misused in teaching, they are recognized as important aids to learning. They can help the teacher to individualize instruction since they permit each student to read at his own rate of comprehension; they are economical in that texts may be used for a number of years: they can help students learn how to study, to read better, and to solve problems; they promote further learning; they give unity to a course and, finally, the printed page reinforces the learning in or out of the classroom by providing the student with reading materials to be studied at different intervals.

In many science classes more than one textbook is available to the students. In all classes at least one textbook should be available to each pupil. Frequently, the science teacher is asked to recommend a science text or several science books for purchase. Mallinson[3] suggests the following criteria in selecting a textbook for high school science.

1. The level of reading difficulty.
2. The style of writing.
3. The nature of illustrations.
4. The suggested supplementary activities.
5. The provision for individual differences.
6. The clarity and organization of materials.

Some science teacher would also consider the manner in which simple-to-complex materials are organized. The level of reading difficulty, especially in terms of vocabulary, should be carefully evaluated for different classes. Frequently, a more advanced textbook is very much desired by a science teacher for most of the students.

Mallinson wrote:

Once a textbook has been selected it should be examined carefully to determine whether or not the difficult terms have been defined and explained either in the text or in the footnotes when they are used for the first time.

If the teacher finds a number of words that are likely to cause difficulty for the students, it may be wise to list them. The students should be given specific instructions in their pronunciations, spellings, and meanings before the words actually appear in the text. Thus, it will not be necessary for the teacher to spend time correcting misconceptions that arise from the pupils' misunderstandings of such words.

Vogel[4] developed an evaluation scale that may be a guide for selecting science textbook. His criteria are grouped under 10 major headings: qualification of the author, organization, content,

3. Mallinson, George G., Some problems of vocabulary and reading difficulty in teaching junior high school science. *School Science and Mathematics*, 52: 269-274, April 1952.
4. Vogel, Louis F., A spot-check evaluation scale for high school science textbooks. *The Science Teacher*, 18: 70-72, March 1951.

presentation, accuracy, readability, adaptability, teaching aids, illustrations, and appearance. A similar rating scale was also developed by Burr.[5]

Whether the selection is to be made by an individual science teacher or by a committee of teachers, it may be helpful to obtain answers to the following questions:

1. Are the major objectives of teaching science being considered in selecting a text?
2. How is the content in the syllabus related to the content in the textbook?
3. Are publishers' catalogues which list new books being examined along with the new texts?
4. What is the quality of the cover, paper, printing, binding, graphic and pictorial aids, study guides, problem-solving activities, film listings and descriptions, bibliographies, and self-evaluation devices?
5. What is the level of difficulty of reading and vocabulary?
6. Is the text attractive and readable to students?
7. Is the text accurate and up-to-date?
8. Does the text have a high interest level?
9. Do the reading materials suggest problem-solving activities?

5. Burr, Samuel, E., *A Rating Scale for Textbooks*, J. of Edu., 132, 138.

11

TEST CONSTRUCTIONS IN SCIENCE

A. Establishlng Test Specifications

1. *Specification of Function and Content*

The first step is to decide what the test is supposed to accomplish. This is easily said, but less easily done. One must specify first the kinds of actions or decisions to be based on test scores. The test might be used as a basis for prediction, for assessing or certifying current competence, or for attempts to understand behaviour. Once the broad purpose is defined, the tester must become more specific and define conceptually the constructs to be measured. In personnel work, these must be relevant to the job situation. In specifying relevant constructs, there is no substitute for observing people at work, studying the results of their work, and asking questions about the results and how they were accomplished.

Specification of Content

A construct is specified when one has stated, as precisely and coherently as possible, his conceptual definition of it. Test development, is, however, the development of operational definitions. As such, a test consists of operations: tasks to be performed or questions to be answered. These stimulus operations are the content of the test.

It is easier to specify in advance the content of an achievement test than of an aptitude test. The content of an aptitude test must be determined empirically; the content of an achievement test is based on the objectives of measurement. Of course, the distinction between achievement aptitude is one of use, not of construction. If one is developing an aptitude test, it is convenient to think of it in the early stages as an achievement test; the result is likely to be a preliminary form that will cover more varieties of content than will be useful in the prediction of future behaviour. The selection of the appropriate content for predictive purposes then becomes an empirical matter.

Two kinds of objectives are important in building achievement tests. These are:

(i) Subject matter objectives, specific bits of knowledge or skill, and (2) process objectives, responses to or manipulations of the subject

matter. The difference was illustrated by Thorndike and Hagen for an examination on labour relations. Subject matter was organized into an outline of six major categories, the first being "The Growth of Organised Labour". Process objectives were to find out whether a tester (1) knows basic terms and concepts, (2) has a 'store' of basic facts, (3) knows sequences of development and of casual relationships, (4) understands broad principles, (5) can apply such principles in new situations, (6) can find and interpret new information, (7) can evaluate evidence critically, and (8) exhibits "socially desirable attitudes and appreciations". All of these can be expressed without reference to subject matter. Any or all of them can dictate the nature of the content of the test, without specifying the topics to be covered.

2. *Specification of Population*

There are obvious reasons for being specific about the population for whom the test is intended. For one, items must be written so that they will be understood by people within that population.

3. *Specificatian of Test and Item Types*

To some degree, the specification of function content, and population may dictate the type of the test to be used. If one's purpose, for example, is to determine skill level in machine operation of specified kind of mechine tools for specified kinds of problems among immigrants who do not speak the language here, he will probably develop a work sample. If the general intellectual level of a group of high school graduates is to be determined with a brief, untimed power test, then some form of paper-end pencil testing is called for.

4. *Free-response Items*

Free-response, sometimes called open-end, items are those in which a task is given or a question asked without imposing any restrictions on the kinds of responses the subject may make, such items may range from simple questions to be answered with perhaps a word or phrase to broad essay items requiring long discussions.

The principal advantage to the free-response item is that it requires the subject to produce the answer rather than to recognize it. This, presumably calls for a somewhat greater depth of knowledge. Such items provide the subject with more opportunity to show how well he can analyze a problem, think through and organise his items, and follow these ideas through to a logical conclusion.

There are several disadvantages to this type of item, depending upon the degree of specificity of the item, the open-end or free-response items will probably result in quite limited coverage of the content. More important, the free-response test is harder to score. This is not merely an inconvenient and expense for the tester, it is also a serious source of unreliability.

5. *Objective Tests*

In contrast to essay examinations are those where only a limited number of responses are possible. Characteristic item types include true-false items and multiple choice items. Tests composed of such items, at least among aptitude and achievement tests, are said to be objective tests.

The major advantage of the objective test is that responses can be unambiguously classified either as right or as wrong answers. The result is a high degree of reliability. Objective tests offer further advantage of permitting the tester to include a broader sampling of test content. Objective tests, of course, call more for recognition than for recall. They are often criticized, therefore, as superficial. This is a presumed rather than a real disadvantage to the objective test. When an objective test is also superficial, it is quite likely that the test builder has been careless or unimaginative in the invention of the test items.

6. *Completion Items*

Strassling between objective tests and free response tests are the completion items. In these a sentence is given with at least one word or phrase omitted. The testee is to fill in the appropriate words. Scoring is somewhat simpler than for easy items, although not objective in the usual sense. Usually more than one response can be written in the missing space; therefore, some flexibility and judgement are often required in scoring. This is tantamount to an admission that scorer unreliability is still a problem with such items.

All too often completion items become absurd, as a glance at many of the work books accompanying textbooks in general psychology will demonstrate rate recall of a specific verbal formula is often necessary. If a completion item is to have any merit, it must be a fairly complete and unambiguous statement, the sense of which is clear to any reasonably well-informed testee.

7. *True-False Items*

Nothing is more easily scored than an item to be marked either "true" or "false", but no other type of item has less to recommend it. It is limited to purely factual items, about which there can be no debate. It is susceptible to contamination from systematic response tendencies of the people tested; some people have greater tendencies "acquiesce" (to mark any item true) than do others and individual differences in this tendency may account for the major portion of the variance in sets of items using this format. Thus the response may well depend on variations in the interpretation of certain words, or on variations in standards of what is true. About all that the true-false format has to recommend it is that it is a fast and easily scored method of getting an assessment of group of factual knowledge but

the same can be said of other test formats which have other virtues as well.

8. *Multiple-Choice Items*

The multiple-choice-item format is not only one of the most common types but it is also one of the most versatile. Such items can be used to test for grasp of factual information or for reasoning ability. Multiple-choice items can be written for definitions of terms; for statements of purposes or objectives for identification of causes, effects, or associations; for recognition and identification of errors; for the evaluation of alternatives; for the detection of differences, similarities, or common principles; for the recognition of steps in sequence; or for understanding the nature of the arguments in a controversy.

There are three parts to a multiple-choice item: the stem, the correct answer, and a series of distracters or wrong answers. A multiple choice item is often an objectively scorable form of the completion test; one of a series of alternatives represents a completion of a statement that is correct or best. The suggestions for good multiple-choice items can be summarised as follows:

First, give each item some "face validity". Every item should be obviously relevant to the announced purpose of the test; moreover, the language should be appropriate, both in level of difficulty and in choice of words.

Second, be sure that there is one correct (or best) answer. Be sure that distracters are false; if all options are partly acceptable, be able to identify a principle by which one answer is clearly better than the others. If the question deals with controversial material, ask for the position held by some specified expert or authority.

Third, make the problem clear in the stem. Although the incomplete sentence is a more concise form, it is often helpful to phrase the stem first as a question, this clarifies in the test builder's thinking the nature of the task he wishes to pose. As much of the item as possible should be in the stem, so that the options are as brief as possible. Brevity, of course, is also desirable in the stem; excess verbiage can create ambiguity care must be taken to eliminate irrelevant material (unless, of course, the problem is to distinguish the crucial aspect of a problem from minor detail).

Fourth, avoid offering cues to the right answer. Many items contain "specific determiners"—cues that enable the testee to identify the preferred option without the desired knowledge. For example, if the stem ends with the article "an" and only one option begins with a vowel, that option is most likely to be chosen. This can be avoided by using the article from "a (n)" or starting each option with the appropriate article.

Fifth, maintain a consistent number of options. If it is necessary to vary the number of options, do it early in the test so that no special sets are established.

Sixth, be sure that the distracters are plausible. A good item is one in which poorly informed subjects distribute their wrong answers rather evenly. A good way to develop plausible distracters is to administer open-end questions to a preliminary sample.

Seventh, keep the distracters homogeneous in content. When every option refers to a different aspect of the problem, each one becomes in effect a single true-false item; the answering is then based more on cleverness in elimination of options than on knowledge or understanding of the material covered by the test. Options must, however, be independent of each other. If two options are merely different ways of saying the same thing, both of these can be quickly *discarded* by the clever judges.

9. *Matching Items*

A potentially excellent text device, one which has the twin virtues of objectivity in scoring and of requiring the testee to think, is the arrangement test. This consists of a number of statements, presented in essentially random order, to be arranged in a proper sequence by the testee.

There are many situations where knowledge of sequence may be important enough to be tested. Objects may be arranged according to size, merit, or complexity. Events or operations in a task may be arranged in chronological order.

B. Specification of Test Budget[1]

By "test budget" is meant an allocation of the total material to the various content areas. This may reflect judgements of the relative importance of the different areas; content validity, however, will be greater if the allocation to cells is proportional to the amount of information in similar cells in the earlier specification of content.

When the total number of items to be included in the test is specified, these percentage statements can be translated into item counts. It is not always easy, however, to specify the total number of items to be included. Legend has it that Lincoln, when asked how long a man's legs should be, replied, "long enough to reach the ground." A similar answer can be given to describe how long a test should be: long enough to cover the ground. Test length is, then, partly a practical matter of what is to be covered in the testing. It is also a matter of time.

C. Specification of Time

Parallel to the specification of the test budget, therefore, is the specification of testing time. This is a two-pronged problem. Its obvious aspect is the setting of actual time limits. A prior question,

1. Guion, *Personnel Testing*.

however, is whether to establish any time limits at all. Most tests do have time limits, but one suspects that they are often established simply for administrative convenience, without psychometric rationale. There should be more caution in using time limits; they may have undesirable consequences for mental measurement. It has been suggested that time limits may be invisible barriers that keep us from access to the mental functions we wish to measure—invisible because we so often neglect to report or describe the speed of our tests.

A distinction is often made, or attempted, between "speed" tests and "power" tests, the latter being those that show that what the individual can do in an unlimited situation, and the former indicating what he can do within the restrictions of time pressures. Some tests have time limits liberal enough that most subjects are expected to be able to finish. Such tests combine elements of the speed test and the power test, and the proportions are likely to be different for different subjects.

Mollinkopt has argued that time limits serve to define the task, and that instructions should make the nature of the relationship of time to performance explicit. His argument is based on the observation that the same test material measures something quite different when given under the different conditions of time limits or of no time limits.

If one is going to develop a speed test, the setting of actual time limits should be done on the basis of empirical evidence. The time limit should be tight enough that no one is able to finish the test; it should be long enough to provide adequate reliability of measurement.

D. Objective Testing[2]

The Principal Advantages of objective testing are:

1. Because the items are short it is possible to include a greater number of items than would be possible using other types of tests. A greater number of items—like a greater number of physical measurements—gives a result of greater precision, i.e., it increases the Reliability of the test.
2. A wide range of syllabus can be convered because the pupil can answer a large number of items in the time allowed without being given a choice of items.
3. In objective testing there is almost complete marker reliability; this is not so in other test forms.
4. Marking of objective tests is much more rapid than with any other type of test. Objective tests can be either machine marked

2. Houston, J.G., *Principles of Objective Testing in Physics.*

or hand marked by unskilled personnel. This is a valuable saving of time and money when the number of candidates is very large, e.g., in a national examination.

5. Objective testing can be readily used for diagnostic purposes by the teacher during the course. The items used are specifically designed to evaluate particular educational objectives. The rapidity of marking gives the teacher the information he requires and gives it in a useful form more quickly than it could be obtained using other types of tests, in which it may be necessary to evaluate all the objectives of a course in order to evaluate any.
6. Using objective testing it is possible to devise a test in which each item evaluate a specific objective.
7. Each item in an objective test can be pretested before it is used in the test so that ambiguities in wording etc., can be discovered. It is also possible that to confirm that each item in the test is of the correct level of difficulty and contributes positively to what the test as a whole is evaluating. Due to the formal objective tests it is easy to produce from the results of pretesting, the statistical evidence on which the suitability of each item for inclusion in the test proper can be judged.
8. In objective tests because the itmes have been pretested the intention of the setter is clear and unambiguous; and the candidate knows precisely what is required for each mark. With other types of tests ambiguity in wording may lead to the candidates submitting answers to questions which the setter did not intend to ask.

II. *The Disadvantages of objective testing are*:

1. Objective testing take much longer to prepare than traditional testing (Essay type). There has to be a large number of items.
2. Objective tests have to be constructed by skilled setters who have been trained in the techniques.
3. Objective items do not test the ability of the candidate to organise information in a logical order and express clearly the development of an extended argument.
4. Objective tests do not stimulate new ideas nor the ability to develop an 'open-ended' situation—the situation is already created for the candidate. The ability to exploit open-ended situations is important in physics and has to be evaluated in another way.
5. The scores (i.e., marks) gained in objective examinations may become unreliable because the candidates have guessed the answers. For this reason it may be considered necessary to take steps to discourage condidates from guessing.

6. There is a tendency to set objective items in physics which test only the ability to recall knowledge. When most or all of the items test only this ability, in preparing for the test students will 'cram' knowledge and the higher abilities will be neglected. This is just as likely to occur with other types of tests but it is perhaps more obvious when the items are of the objective type.
7. Because of the difficulty in making up objective tests there is an understandable desire to retain good items for future use. It is therefore essential to be punctilious about collecting the question papers after use so that the items are kept secure between tests.

III. *Guessing in Objective Tests*

The reliability of marks in an objective test is reduced where the pupils have scored marks by guessing. A good objective test is designed in such a way that guessing is reduced to a minimum.

When a large number of pupils attempt a test which consist of 100 true/false items and have no knowledge whatever of physics but make completely random guesses at all the items they will an average answer 50 of the items correctly. This is not a realistic situation: it is more likely that the pupils know some of the items and guess at the rest. It is impossible to tell whether he answered correctly because he guessed correctly. Neither is it possible to tell whether he answered an item wrongly because he possessed wrong information or because he guessed wrongly. Where the test is being used for diagnostic purposes the teacher might want to know these things, and wants discourage his pupils from guessing. For these reasons when true/false items, or items in which a pupil has to select an answer from two alternatives, are used correction has to be applied to the pupils' marks which takes account of the fact that pupils have guessed at least some of the items.

Formulae used to correct scores for guessing assume that, faced with a selection item, the pupil either knows the correct response or has no knowledge whatever and makes a completely random guess. In fact, the pupil's response to the item is rarely polarised in this way. He may not be absolutely sure of the correct response but is likely to have sufficient knowledge to permit him to eliminate some of the distracters and guess between those left. Correction formulae do not take account of this kind of guessing.

IV. *Correction for Guessing*

There are two ways in which pupils can be discouraged from guessing in objective tests.

1. By employing a penal guessing formula, e.g., by deducting a mark from the pupils' score for each item wrong. Where a harsh correction formula is used the pupil is discouraged from completing the test: it is more profitable to leave an item unattempted when a mark is deducted for each item wrong.

2. By using well-constructed and pretested items such as multiple choice four or five response items in which the pupil is discouraged from guessing by the number of alternative responses provided, and by the plausibility of the distracters offered.

V. *Correction Formulae*[3]

One correction formula commonly used to adjust scores for guessing is described below. It assumes:

(i) That all guessing is random guessing.

(ii) That all wrong items are wrong because the pupil guessed wrongly and not because he had wrong knowledge.

It follows from (i) that as the number of responses provided increases the chances of getting an item correct by guessing above decreases.

No. of responses	*Chance of being correct by guessing*	*Chance of being wrong by guessing*
2	1 in 2	1 in 2
3	1 in 3	2 in 3
4	1 in 4	3 in 4
5	1 in 5	4 in 5

Where a candidate guesses his response to multiple choice items with four/five responses is likely on average to answer only ONE item correctly for every three/four items. He answers wrongly; cf. true/false items where guessing gives ONE item correct for every wrong item.

The marker of an objective test cannot tell whether a wrong answer results from guessing or from wrong knowledge. Where it is assumed that All wrong items are the results of 'bad' guessing—(ii) above—in a test comprising multiple choice five response items, for every four items a pupil answers wrongly it follows that he answers. ONE item correctly, also by guessing. Should he answer twelve items wrongly by guessing it is reasonable to assume that he answered three items correctly by guessing and three marks therefore be deducted from his score.

Example

A pupil answers 28 items correctly in a test consisting of 40 multiple choice five response items. It is assumed that he has all 12 items wrong because he guesses incorrectly. For every 4 items he answers wrongly by guessing he answers one item correctly by guessing. He has 12 items wrong so that he must also have 3 items correctly guessing. Three marks are therefore, subtracted from his score, i.e.,

3. Houston, J.G., *Ibid*.

$$\text{Corrected Score} = 28 - \frac{12}{4} = 25$$

In general

$$\text{Corrected Score} = \text{Original Score} - \frac{\text{No. of items wrong}}{\text{No. of responses} - 1}$$

$$R = R - \frac{W}{n - 1}$$

Where R_c is the corrected score

R is the number of items the pupil has correct
W is the number of items the pupil has wrong (assumed all as a result of guessing).
n is the number of responses per item. The correction factor $\frac{W}{n-1}$ decreases as the number of responses increases. It is probably not worthwhile using a correction formula where four or more responses are offered.

VI. *Disadvantages of Correction Formulae*

Correction formulae should not be used except in special cases because:

1. In a good test, that is one in which the distracters have been designed to appeal to candidates with wrong knowledge or low understanding, few of the wrong responses will be due to guessing. In that case a correction formula will be an over correction.

2. Even where all wrong items are due to random guessing, pupils' marks will be differentially corrected since the formula assumes that random guessing in, for example, five response items will ALWAYS result in four wrong items for every correct item. This is true only 'on average.' Some pupils will be luckier in guessing than others.

3. Correction for guessing makes no difference to the rank order of marks of ALL pupils complete ALL items in the test. This can be shown as follows. Correction formula:

$$Rc = R - \frac{W}{n-1}$$

and

$W = N - R$ Where N = the total No. of items in the test.

$$Rc = R - \frac{(N-R)}{n-1} = \frac{R(n-1)-(N-R)}{n-1}$$

$$= \frac{n}{n-1} \times R \frac{N}{n-1}$$

and $\frac{dR_c}{dR} = \frac{n}{n-1}$, which is also a constant i.e.,

increases in R_c are directly proportional to increases in R, and the rank order of marks is not changed by the use of the correction formula.

4. Pupils should be encouraged to complete the test even by guessing so that all are assessed on the same scale. The use of a correction formula discourages pupils from guessing.

5. In a good test pupils will not make random guesses but will eliminate the distracters which they know to be wrong and guess amongst the responses left. Guessing correction formulae are appropriate only where random guessing has occured.

Correction formula should be applied only where it is essential that the pupils be discouraged from guessing. There use may be justified in the following cases:

(*i*) Where the test is being used for diagnostic purposes. Guessing destroys the diagnostic value of the test since it disguises the pupils' weaknesses. A teacher may want to know whether a pupil answered a particular item correctly because he knew the answer or because he was lucky enough to guess correctly.

(*ii*) Where the test comprises items such as true/false in which the item form makes guessing a worthwhile enterprise from the pupil's point of view.

Where the test is a good one consisting of multiple choice items with four or more responses and the items have distracters which are attractive to pupils with wrong information there is unlikely to be much random guessing because:

(*i*) The item type makes random guessing unprofitable. In a 100 item test of multiple choice five response items where 1000 pupils make random guesses at all the items, their marks would range from 7 to 33 per cent. None would score half marks. The average mark for the test would be about 20 per cent.

(*ii*) Pupils will get items wrong not by guessing but because they think that one of the distracters is correct.

In conclusion, where the purpose of an object test is to establish a rank order of marks the use of correction formulae is of little value. In a good objective test little random guessing will occur.

Objective-Type Tests in Physical Sciences: For evaluating the students with respect to different objectives of Physical Sciences, the author has constructed a battery of six objective-type tests. These tests cover the following aspects of Physics and Chemistry.

Physics

Test No. 1. Facts and Technical Terms
Test No. 2. Principles, Laws and their Applications
Test No. 3. Numericals

Chemistry

Test No. 1. Facts, Symbols, formulae and Chemical Equations
Test No 2. Chemical laws, Properties and their Applications
Test No. 3. Numericals

PHYSICS TEST NO. 1 (FACTS & TECHNICAL TERMS)*

Time—40 mts. Max. Marks = 38

INSTRUCTION

Put an √ mark in the answer box □ opposite to the correct answer in the following questions.

1. The centripetal force is given by the expression:
   1. $\frac{mv^2}{r^2}$ □
   2. mvr □
   3. $\frac{mv^2}{r}$ □
   4. $\frac{mr^2}{v}$ □
2. Cm/sec² stands for the unit of
   1. Acceleration □
   2. Force □
   3. Moment □
   4. Energy □
3. When a mirror is rotated through an angle θ, the reflected ray will be rotated by:
   1. Angle θ □
   2. Angle 2θ □
   3. Angle$\theta/2$ □
   4. Angle 4θ □
4. An isolated N—pole placed in a magnetic field:
   1. Will move in the direction of the field □
   2. Will move in a direction opposite to that of field □
   3. Will remain stationary □
   4. Will move at right angles to the direction of the field □
5. Pick out the scalar quantity from the following:
   1. Energy □
   2. Force □
   3. Velocity □
   4. Momentum □
6. Magnetic moment can be measured by a:
   1. Pyromter □
   2. Deflection Magnetometer □
   3. Hypsometer □
   4. Dynamometer □

*Gupta, Sharwan Kumar, Factor Analysis of Higher Secondary/Pre-University passed students in different aspects of Physical Sciences and Mathematics, Ph.D. Thesis 1974, Kurukshetra University, p. 149.

7. The dimensional formula of angular velocity is:
   1. $ML T^{-1}$ ☐
   2. $ML^{\circ} T^{-2}$ ☐
   3. $M^{\circ}L^{\circ} T^{-1}$ ☐
   4. $M^{\circ}L^{\circ} T^{\circ}$ ☐
8. Mass is given by the relations
   1. $\frac{\text{Velocity}}{\text{Acceleration}}$ ☐
   2. $\frac{\text{Force}}{\text{Velocity}}$ ☐
   3. $\frac{\text{Force}}{\text{Acceleration}}$ ☐
   4. $\frac{\text{Distance}}{\text{Velocity}}$ ☐
9. Watt stands for the unit of
   1. Force ☐
   2. Work ☐
   3. Power ☐
   4. Charge ☐
10. Solar eclipse is seen when:
    1. The moon comes in between the sun and the earth ☐
    2. The earth comes in between the sun and the moon ☐
    3. The sun comes in between the earth and the moon ☐
    4. The line joining the centres of the moon and the earth is perpendicular to the line joining the centres of the earth and the moon ☐
11. When rays from the sun pass through a glass prism, the emergent beam shows all colours of the rainbow. This is so because;
    1. The prism adds colours to the sun light ☐
    2. Sun light is split into its constituent colours ☐
    3. The screen that receives the emergent beam produces these colours ☐
    4. The air on the other side of the prism adds colours to the emergent beam ☐
12. The acceleration due to gravity is:
    1. 9.80 meter/Sec ☐
    2. 9.80 meter/Sec ☐
    3. 980 meter/Sec ☐
    4. 32 cm/Sec^2 ☐
13. Check the correct relation:
    1. $\text{Ohm} = \frac{\text{ampere}}{\text{volt}}$ ☐
    2. $\text{Volt} = \frac{\text{volt}}{\text{ampere}}$ ☐
    3. $\text{Ohm} = \frac{\text{volt}}{\text{ampere}}$ ☐
    4. $\text{Ohm} = \text{volt} \times \text{ampere}$ ☐
14. Water has maximum density at:
    1. 0°C ☐
    2. 32°F ☐
    3. −4°C ☐
    4. 4°C ☐
15. In the visible spectrum the colour having the shortest wavelength is:
    1. Red ☐
    2. Yellow ☐
    3. Blue ☐
    4. Violet ☐
16. The dimension of work is
    1. ML^2T^{-2} ☐
    2. M^2LT^{-2} ☐

3. $ML^{-2}T^{2}$ ☐
4. MLT^{-1} ☐

17. When milk is churned, the cream separates from it due to the:
    1. Cohesive force ☐
    2. Centrifugal force ☐
    3. Frictional force ☐
    4. Gravitational force ☐
18. Coefficient of volume expansion is:
    1. Equal to the coefficient of linear expansion ☐
    2. Twice the coefficient of linear expansion ☐
    3. Thrice the coefficient of linear expansion ☐
    4. Less than the coefficient of linear expansion ☐
19. Coefficient of superficial expansion is:
    1. Less than the coefficient of linear expansion ☐
    2. Equal to the coefficient of linear expansion ☐
    3. Twice the coefficient of linear expansion ☐
    4. Thrice the coefficient of linear expansion ☐
20. The nucleus of an atom generally contains:
    1. Protons, electrons ☐
    2. Protons, neutron, electrons ☐
    3. Electrons, neutrons ☐
    4. Protons, neutrons ☐
21. The heat which is used up in changing the state of a body without raising its temperature is called:
    1. Calorofic value ☐
    2. Specific heat ☐
    3. Latent heat ☐
    4. Thermal capacity ☐
22. Dimension of pressure is:
    1. $ML^{-1}T^{-2}$ ☐
    2. $ML^{-2}T^{-1}$ ☐
    3. $ML^{-2}T^{-1}$ ☐
    4. $M^{-1}LT^{2}$ ☐

I3. In phosphorescence:
    1. The wavelength of light emitted is greater than that of the incident light ☐
    2. The wavelength of light emitted is shorter than that of incident light ☐
    3. The wavelength of light emitted and that of incident light are equal ☐
    4. The wavelength of light emitted may be greater or less than that of the incident light ☐

24. The density of water is:
    1. 10^{6} Kg./meter^{3} ☐
    2. 10^{3} Kg./meter^{3} ☐
    3. 1.0 Kg./meter^{3} ☐
    4. 10^{-3} Kg./meter^{3} ☐
25. The refractive index of glass is least for:
    1. Red light ☐
    2. Yellow light ☐
    3. Violet light ☐
    4. Green light ☐
26. Water is boiling in a flask over a burner:
    To reduce its boiling temperature one must:
    1. Reduce the surrounding temperature ☐
    2. Connect the mouth of the flask to an evacuating system ☐

3. Supply heat from a less intense source ☐
4. Connect the mouth of the flask to a compressor ☐

27. For a gm—molecule of an ideal gas:
1. $\frac{PV}{T}=2$ calories ☐
2. $\frac{PV}{T}=4.31$ calories ☐
3. $\frac{PV}{T}=4.2$ calories ☐
4. $\frac{PV}{T}=4.2\times 10^7$ ergs ☐

28. The temperature to which a gas must be cooled before it can be liquefied by pressure alone is called its:
1. Boiling point ☐
2. Saturation point ☐
3. Critical temperature ☐
4. Freezing point ☐

29. In induction the charge induced in the near surface of the conductor:
1. Is similar ☐
2. Is dissimilar ☐
3. May be similar or dissimilar depending upon the distance between them ☐
4. Is zero ☐

30. Two mirrors are placed perpendicular to each other. A ray strikes the first mirror and after reflection from the first mirror it falls on the second mirror. The ray after reflection from the second mirror will be:
1. Perpendicular to the original ray ☐
2. Parallel to the original ray ☐
3. At 45^0 to the original ray ☐
4. At $6C^0$ to the original ray ☐

31. A liquid boils at the temperature at which the pressure of the saturated vapour becomes:
1. Less than the atmospheric pressure ☐
2. More than the atmospheric pressure ☐
3. Equal to the atmospheric pressure ☐
4. Equal to twice the atmospheric pressure ☐

32. The value of acceleration due to gravity for earth is:
1. Greater at equator than at poles ☐
2. Greater at the poles than at the equator ☐
3. Same at equator as at poles ☐
4. Greater at the equator than at latitude 45^0 N ☐

33. Universal gas constant has the unit:
1. dynes/C° ☐
2. ergs/K° ☐
3. ergs cm/K° ☐
4. Watt/K° ☐

34. A neutral point in the magnetic field is a point where:
1. The magnetism is strongest ☐
2. The earth's field is zero ☐
3. The field due to the magnet is zero ☐
4. The resultant magnetic intensity is zero ☐

35. Colour of light is determined by:
    1. Velocity in air □
    2. Amplitude □
    3. Frequency □
    4. State of polarization □

36. A piece of stone tied at one end of a piece of string is being whirled in a circle in the horizontal plane with constant speed, then:
    1. Its Kinetic Energy will go on increasing □
    2. Its Kinetic Energy will go on edcreasing □
    3. Its Kinetic Energy remains constant □
    4. The centripetal force will work up on it □

37. A earth satellite is kept moving in its orbit by the centripetal force provided by:
    1. The gravitational attraction of the earth on the satellite □
    2. The rocket engine attached to the satellite □
    3. The gravitational attraction of the sun on the satellite □
    4. The radio wave sent by the ground station to the satellite □

38. The number of images of an object placed between two parallel mirrors is:
    1. Two □
    2. Four □
    3. Six □
    4. Infinite □

Answers

1. (3), 2. (1), 3. (2), 4. (1), 5. (1), 6. (2), 7. (3), 8. (3), 9. (3), 10. (1) 11. (2), 12. (1), 13. (3), 14. (4), 15. (4), 16. (1), 17. (3), 18. (3), 19. (3), 20. (4), 21. (3), 22. (1), 23. (1), 24. (2), 25. (1), 26. (2), 27. (1), 28. (3), 29. (2), 30. (2), 31. (3), 32. (2), 33. (2), 34. (4), 35. (3), 36. (3), 37. (1), 38. (4).

PHYSICS TEST NO. 2 (PRINCIPLES & THEIR APPLICATIONS)*

Time—40 mts.

Max. Marks = 32

INSTRUCTION

Put a √ mark in the answer box □ opposite to the correct answer in the following questions.

1. When a moving train stops suddenly, the passenger will:
    1. Fall backward □
    2. Fall forward □
    3. Jump headway □
    4. Remain stationary □

2. The purity of gold is tested by:
    1. Faraday's laws of electrolysis □
    2. Archimedes Principle □
    3. Charle's Law □
    4. Pascal's Law □

*Gupta, Sharwan Kumar, *ibid.*, p. 151.

3. Sudden fall in the reading of a barometer means the approach of a :
   1. Storm ☐
   2. Fair weather ☐
   3. Cold wave ☐
   4. Hot wave ☐
4. A straight stick partly immersed in water appears bent due to:
   1. The phenomenon of reflection of light ☐
   2. The phenomenon of refraction of light ☐
   3. The phenomenon of transmission of light ☐
   4. The phenomenon of total internal reflection ☐
5. When a body floats in a liquid its weight is equal to the weight of the liquid displaced. This is known as:
   1. The principle of conservation of weight ☐
   2. Principle of equilibrium ☐
   3. Principle of floatation ☐
   4. Principle of conservation of momentum ☐
6. It takes more time to cook vegetables, meat and pulses, etc., at the mountains because there:
   1. The atmospheric pressure is decreased ☐
   2. The atm. pressure is increased ☐
   3. The temperature is lowered ☐
   4. The quantity of O_2 in air is reduced ☐
7. The weight of a body is reduced at the moon due to the reduction in:
   1. Density of the body ☐
   2. Mass of the body ☐
   3. Gravity of the body ☐
   4. Specific gravity of the body ☐
8. Water keeps cool in an earthen pot in summer because:
   1. Earthen pot does not allow heat to enter through its thick walls ☐
   2. It reflects heat radiations falling on it ☐
   3. It helps water to radiate heat and thus becomes cooler ☐
   4. It helps water to ooz out and gets evaporated ☐
9. Bramah Press works on the:
   1. Newton's third law of motion ☐
   2. Principle of equilibrium ☐
   3. Pascal's law ☐
   4. Archimede's Principle ☐
10. A piece of wood floats in water because:
    1. The total weight of water displaced by it is less than its weight ☐
    2. The total weight of water displaced by it is equal its weight ☐
    3. The total weight of water displaced by it is greater than its weight ☐
    4. Its density is less than water ☐
11. Use of Leclanche cell is most suited for:
    1. Telegraphy ☐
    2. Ringing electric bells ☐
    3. Electrolysis ☐
    4. Electro-plating ☐

12. Heat Engines work on the principle:
    1. The heat is converted into sound energy ☐
    2. The heat is converted into mechanical energy ☐
    3. The heat is converted into light energy ☐
13. Clothes keep us warm in winter because they:
    1. Supply extra heat to body ☐
    2. Do not radiate heat ☐
    3. Prevent the heat of the body from escaping ☐
    4. Prevent air to enter the body ☐
14. Centrifuge machines depend for their working on:
    1. Centripetal force ☐
    2. Centrifugal force ☐
    3. Gravitational force ☐
    4. Electrostatic force ☐
15. A Pressure Cooker, useful to cook meals at mountains, is based for its working on:
    1. It reduces the boiling point after increasing the vapour pressure ☐
    2. It increases the boiling point after increasing the vapour pressure ☐
    3. It reduces boiling point after reducing vapour pressure ☐
    4. It increases boiling point after reducing vapour pressure ☐
16. A rocket works on the principle of:
    1. Conservation of mass ☐
    2. Conservation of Energy ☐
    3. Conservation of linear momentum ☐
    4. Conservation of angular momentum ☐
17. The lightning-conductor protects the building from the lightning by:
    1. Not permitting the lightning to fall on the building at all ☐
    2. Driving away the charged clouds ☐
    3. Forcing the lightning to fall on other buildings in the neighbourhood ☐
    4. Conducting the electric charge to the ground when lightning strikes the building ☐
18. A monkey is at rest on a weightless rope which goes over a pulley and is tied to a bunch of bananas at the other end. The bunch of bananas weigh exactly the same as the monkey. The pulley is frictionless and of negligible mass. The monkey starts to climb up the rope to reach the bananas. As he climbs, the distance between him and the bananas:
    1. Decreases ☐
    2. Increases ☐
    3. Remains the same ☐
    4. First decreases then increases ☐
19. Cloudy nights are warmer than clear nights because:
    1. Clouds radiate heat to the ground ☐
    2. Clouds prevent radiation of heat from the ground and air ☐

3. In the presence of clouds, living beings absorb more heat ☐
4. Clouds transmit us heat by convection ☐

20. Railway tracks are banked on curves so that:
1. Necessary centripetal force may be obtained from the horizontal component of the weight of the train ☐
2. The train may not fall down inward ☐
3. No frictional force may be produced between the wheels and the track ☐
4. The weight of the train may be reduced ☐

21. Air conditioning in a hall is the process of:
1. Lowering the temperature of hall ☐
2. Heating the hall ☐
3. Regulating humidity, temperature and circulation of air ☐
4. Lowering the humidity of the hall ☐

22. In an oil lamp holes provided below the chimney:
1. Serve to bring in oxygen for burning of oil ☐
2. Maintain the convection currents to keep lamp burning ☐
3. Provide an outlet for the smoke to escape ☐
4. Increase the brightness of the lamp ☐

23. The sky appears blue because:
1. There is more blue colour in sunlight than any other colour ☐
2. Short waves are scattered more than the long waves by atmosphere ☐
3. The eye is more sensitive to blue ☐
4. The atmosphere absorbs long wavelengths more than short wavelengths ☐

24. A direct vision spectroscope is constructed on the principle of:
1. Deviation without dispersion ☐
2. Dispersion without deviation ☐
3. Selective absorption ☐
4. Diffusion ☐

25. Lectometer is used to test milk by checking:
1. Density of the milk ☐
2. Specific gravity of the milk ☐
3. Ratio of milk and water ☐
4. Gravity of the milk ☐

26. A jet plane flies in air because:
1. The thrust of the jet compensates for the force of gravity ☐
2. The weight of air whose volume is equal to the volume of the plane is more than the weight of the plane ☐
3. The flow of air around the wings causes an upward force of gravity ☐
4. The gravity does not act on bodies moving with high speed ☐

27. The phenomenon of nuclear fission is used in the construction of:
   1. The hydrogen bomb □
   2. The atom bomb □
   3. An ordinary bomb □
   4. Not in any of the above □

28. The phenomenon of mirage occurs on account of:
   1. Reflection of light from highly polished ground □
   2. Reflection of particles from sound particles □
   3. Refraction of light in air whose refractive index increases with height □
   4. Refraction of light in air whose refractive index decreases with height □

29. A hygrometer measures
   1. The moisture content of a hygroscopic substance □
   2. Amount of water vapour in air □
   3. Relative density of liquids □
   4. Relative density of air □

30. The core of a transformer is laminated so that:
   1. Ratio of voltages in the primary and secondary may be increased □
   2. Energy losses due to eddy currents may be minimised □
   3. The weight of transformer may be reduced □
   4. Rusting of core may be stopped □

31. What change occurs in the heating effect of a certain electric circuit in which the total resistance is cut in half?
   1. The heating effect is reduced to half □
   2. The heating effect is doubled □
   3. No effect □
   4. The heating effect is increased four times □

32. How should people wearing spectacles work with a microscope?
   1. They should keep on wearing their spectacles □
   2. They should take off their spectacles □
   3. They may either put on their spectacles or they may take off the spectacles, it makes no difference □
   4. They cannot use the microscope at all □

Answers

1. (2), 2. (2), 3. (1), 4. (2), 5. (3), 6. (1), 7. (3), 8. (4), 9. (3), 10. (2), 11. (2), 12. (2), 13. (3), 14. (2), 15. (1), 16. (3), 17. (4), 18. (3), 19. (2), 20. (1), 21. (3), 22. (2), 23. (2), 24. (2), 25. (2), 26. (1), 27. (2), 28. (4), 29. (2), 30. (2), 31. (1), 32. (2).

PHYSICS TEST NO. 3 [NUMERICALS]*

Time—40 mts. Max. Marks—32

Note: **Put a $\surd$ mark in the box opposite to the correct answer in the following questions.**

1. A body weighs 6000,000 dynes on the surface of the earth. If acceleration due to gravity on the surface of moon is one-sixth of the acceleration due to gravity on the earth, then what will be the weight of the body on the moon?
   1. 60,00,000 dynes ☐
   2. 60,00 dynes ☐
   3. 10,00,000 dynes ☐
   4. 3,60,00,000 dynes ☐

2. If two forces F and F acting at a point give as the resultant a force of magnitude F. Then the angle between these two forces must be:
   1. 0° ☐
   2. 120° ☐
   3. 60° ☐
   4. 90° ☐

3. A stone tied to the end of a 20 cm. long string is whirled in a horizontal circle. If the centripetal acceleration is a 980 cm/Sec², its angular velocity is:
   1. 7 radians/Sec. ☐
   2. 14 radians/Sec. ☐
   3. $\frac{22}{7}$ radians/Sec. ☐
   4. 20 radians/Sec. ☐

4. A body is thrown vertically upward with a velocity of 980 cm/Sec. How long will it take to come to the ground?
   1. $\frac{1}{2}$ Sec. ☐
   2. 1 Sec. ☐
   3. 3 Sec. ☐
   4. 2 Sec. ☐

5. A body is thrown vertically upward with a velocity of 980 cm/Sec. How high will it rise?
   1. 90 cm ☐
   2. 1960 cm. ☐
   3. 490 cm. ☐
   4. 245 cm. ☐

6. Two thin lenses of focal lengths f_1 and f_2 are in contact. The combination will act as a thin lense of focal length:
   1. $\frac{f_1 + f_2}{2}$ ☐
   2. $\frac{f_1 f_2}{f_1 + f_2}$ ☐
   3. $\frac{f_1 + f_2}{f_1 f_2}$ ☐
   4. $\frac{f_1^2}{f_1 + f_2}$ ☐

7. The potential due to a charge 10 units at a point which is at a distance of 5 cm. from the charge is given by:
   1. 5 Units ☐
   2. 2 Units ☐
   3. 50 Units ☐
   4. 1/2 Units ☐

8. The refractive indices of turpentine and water with respect to air are 1.5 and 1.3 respectively. Then the refractive index of turpentine with respect to water is:
   1. 13/15 ☐
   2. 15/13 ☐

*Gupta, Sharwan Kumar, *ibid.*, p. 153.

3. 2.8
4. 02

9. A Stationary gun of a mass M fires a bullet of mass m with a velocity V the gun will require velocity:
1. $\frac{MV}{m + M}$
2. $\frac{mV}{M}$
3. $\frac{M + mV}{M}$
4. $\frac{M + m}{MV}$

10. A thin convex lense of focal length 10 cm. is placed in contact with a thin concave lens of the same material and the same focal length, the combination will have a focal length equal:
1. 20 cm.
2. 5 cm.
3. Zero
4. Infinity

11. A perfect gas at 27°C is heated at constant pressure so as to double its volume. The temperature of the gas will be:
1. 54°C
2. 600°C
3. 327°C
4. 300°C

12. If 10 g. of ice at 0°C are mixed with 10 g of water at 10°C the final temperature t is:
1. Given by $10 \times 80 + 10\,(t-0) = 10\,(10-t)$
2. Given by $10 \times 82 = 10\,(10-t) + 10(t-0)$
3. 5°C
4. 0°C

13. A body of mass 100 gm. has specific heat 0.09 calories per gm. Its thermal capacity is:
1. 9 calories
2. 100/9 calories
3. 90 calories
4. 9/100 calories

14. Five dry cells of EMF 1.5 volts are connected in parallel. The EMF of combination is:
1. 7.5 Volts
2. 0.3 Volt
3. 3.0 Volts
4. 1.5 Volts

15. A bucket contains some transparent liquid and its depth is 40 cm. On looking from above the bottom appears to be raised by 8 cm. The refractive index of the liquid is:
1. 5/4
2. 4/5
3. 8/5
4. 1/5

16. Two thin lenses, one of focal length 20 cm. and another of focal length (—40 cm.) are in contact. What is the focal length of the combination?
1. —20 cm.
2. 0 cm.
3. +20 cm.
4. +40 cm.

17. A tensile force of 2×10^5 dynes doubles the length of a rubber card of cross-sectional area 2 Sq. cm. the Young's Modulus of rubber is:
1. 4×10^5 dynes/cm^2
2. 1×10^5 dynes/cm^2
3. 2×10^5 dynes/cm.
4. 3×10^4 dynes/cm.

18. Two condensers of capacities 2 μf and 4 μf are connected in series. The combination will have a capacitance equal to:
    1. 3 μf ☐
    2. 6 μf ☐
    3. 4 μf ☐
    4. 4/3 μf ☐
19. A hollow sphere of metal is given charge +Q. Its radius is R. Then the potential:
    1. On the surface is Q/R and inside also Q/R ☐
    2. On the surface Q/R and inside zero ☐
    3. On the surface zero and inside also zero ☐
    4. On the surface zero and inside Q/R ☐
20. The pole strength of a bar magnet is 50 units. It is cut into two pieces such that the length of one piece is 3 times the length of the other. Compare the pole strength of these two pieces:
    1. 3:1 ☐
    2. 1:1 ☐
    3. 1:3 ☐
    4. 9:1 ☐
21. A charged parallel plate condenser with air between the plates has been insulated. Now the space between the plates is completely filled with an insulator of dielectric constant 5. The capacity of the condenser:
    1. will increase 5 times ☐
    2. will not change at all ☐
    3. will decrease to 1/5 of previous value ☐
    4. will increase 25 times ☐
22. Three dry cells of internal resistance 1 Ohm each are connected in parallel. This combination of cells will have an internal resistance of:
    1. 1 Ohm ☐
    2. 1/3 Ohm ☐
    3. 3 Ohms ☐
    4. 1 Ohm ☐
23. The refractive index of a medium is 1.8. A bubble lies in this medium at an apparent depth of 10 cm. The real depth of the bubble is:
    1. $\frac{10}{1.8}$ ☐
    2. 18 cm. ☐
    3. 12 cm. ☐
    4. 9 cm. ☐
24. The magnetic field due to a short bar magnet at a point in Tan A position at distance x cm. from the middle point of the magnet is 200 Gauss. Then the magnetic field at a point Tan B position at the same distance will be:
    1. 200 Gauss ☐
    2. 400 Gauss ☐
    3. 100 Gauss ☐
    4. 50 Gauss ☐
25. The critical angle for a medium is 60°, then the refractive index of the medium will be:
    1. $\frac{\sqrt{3}}{2}$ ☐
    2. $\frac{2}{\sqrt{3}}$ ☐
    3. $\sqrt{\frac{1}{3}}$ ☐
    4. $\sqrt{3}$ ☐
26. A double convex lens ($\mu=1.5$) in air has its focal length equal to 10 cm. When immersed in water ($\mu=\frac{4}{3}$) its focal length will be:

1. 40/3 cm. ☐
2. 7.5 cm. ☐
3. 40 cm. ☐
4. Infinite ☐

27. An electric current exists in a long wire. At distance of 2 cm. from the wire the magnetic field is 0.2 gauss. What will be the field at 4 cm. from the wire?
1. 1/20 Gauss ☐
2. 0.4 Gauss ☐
3. 0.1 Gauss ☐
4. 0.05 Gauss ☐

28. Three condensers of capacities .2μf, .1μf and .5μf are connected in parallel. The total capacity of the arrangement is:
1. $\frac{1}{17}\mu f$ ☐
2. 17 μf ☐
3. 0.8 μf ☐
4. 1/.8 μf ☐

29. An object is placed between two plane mirrors set at 60° to each other. The number of images seen will be:
1. 5 ☐
2. 3 ☐
3. 2 ☐
4. 6 ☐

30. The frequency of transverse vibration of a string is 400 per Sec. If the tension is increased 4 times, its frequency will be:
1. 1600 per Sec. ☐
2. 100 per Sec. ☐
3. 200 per Sec. ☐
4. 800 per Sec. ☐

31. The sound of frequency 512/Sec. is higher than the sound of frequency 256/Sec. by:
1. One octave ☐
2. Two octave ☐
3. Half an octave ☐
4. Three octave ☐

32. Refractive index of water 4/3 velocity of light in vacuum is 3×10^{10} cm./Sec. Then velocity of light in water will be:
1. 2.25×10^{10} cm/Sec. ☐
2. 4×10^{10} cm/Sec. ☐
3. $13/3\times10^{10}$ cm/Sec. ☐
4. $5/3\times10^{10}$ cm/Sec. ☐

Answers

1. (3), 2. (2), 3. (1), 4. (2), 5. (3), 6. (2), 7. (2), 8. (2), 9. (2). 10. (4), 11. (3), 12. (1), 13. (1), 14. (4), 15. (1), 16. (4), 17. (2), 18. (4), 19. (1), 20. (2), 21. (1), 22. (2), 23. (2), 24. (3), 25. (2), 26. (3), 27. (3), 28. (3), 29. (1), 30. (4). 31. (1), 32. (1).

CHEMISTRY TEST NO. I [SYMBOL, FORMULAE & EQUATIONS]*

Time—40 mts. Max. Marks—30

Note: **Put a √ mark in the box opposite to the correct answer in the following questions.**

1. The chemical formula for Ammonia gas is:
1. NH_2 ☐
2. NH_1 ☐
3. NH_3 ☐
4. NH_6 ☐

*Gupta, Sharwan Kumar, *ibid.*, p. 155.

2. Ca stands for the chemical symbol of:
   1. Carbon ☐
   2. Carbonate ☐
   3. Calcium ☐
   4. Catalyst ☐
3. Pb stands for the chemical symbol of:
   1. Silicon ☐
   2. Lead ☐
   3. Phosphorus ☐
   4. Bismuth ☐
4. The chemical formula for Sodium Chloride is:
   1. $Na\ ClO_3$ ☐
   2. $Na_2\ ClO_3$ ☐
   3. $Na\ (ClO_3)_2$ ☐
   4. $Na\ ClO_2$ ☐
5. The common name for $CaCo_3$ is:
   1. Lime Water ☐
   2. Gypsum ☐
   3. Chalk ☐
   4. Plaster of Paris ☐
6. The chemical name of $K_2\ Cr_2\ O_7$ is:
   1. Potassium Permanganate ☐
   2. Potassium Chromate ☐
   3. Potassium Chromite ☐
   4. Potassium Dicromate ☐
7. If E, A, M and V be respectively the equivalent weight, atomic weight, molecular weight and velancy of an element, the only true equation is:
   1. $A=V\times E$ ☐
   2. $M=A\times V$ ☐
   3. $E=\frac{M}{V}$ ☐
   4. $V=\frac{M}{E}$ ☐
8. K stands for the chemical symbol of:
   1. Sodium ☐
   2. Potassium ☐
   3. Strontium ☐
   4. Aluminium ☐
9. Hg stands for the chemical symbol of:
   1. Hydrogen gas ☐
   2. Gold ☐
   3. Silver ☐
   4. Mercury ☐
10. The chemical name of the Salt $Na\ HSO_4$ is:
    1. Sodium sulphite ☐
    2. Sodium bisulphite ☐
    3. Sodium bisulphate ☐
    4. Sodium sulphate ☐
11. The Equation in accordance with the gas laws is:
    1. $P_1V_1T_1=P_2V_2T_2$ ☐
    2. $\frac{P_1V_1}{P_2V_2}=\frac{T_1}{T_2}$ ☐
    3. $\frac{P_1T_1}{V_1}=\frac{P_2T_2}{V_2}$ ☐
    4. $\frac{V_1T_1}{P_1}=\frac{V_2T_2}{P_2}$ ☐
12. When Potassium Chlorate is heated, oxygen gas is evolved, the correct balanced equation is:
    1. $3K\ ClO_3 =3K\ ClO+2O_2$ ☐
    2. $2K\ ClO_3 =2K\ Cl+3O_2$ ☐
    3. $5K\ ClO_3 =5K\ Cl+6O_2+3O$ ☐
    4. $K\ Cl_2=K\ Cl+O_2+O$ ☐
13. When H Cl is reacted with calcium carbonate the correct and balanced equation representing the chemical reaction is:
    1. $Ca\ CO_3+H\ Cl=Ca\ Cl+H\ CO_3$ ☐
    2. $Ca\ CO_3+2H\ Cl= Ca\ Cl_2+CO_2+H_2O$ ☐

3. $CaCO_3+2HCl=$
$CaCl_2+H_2O+O_2$ □
4. $2CaCO_3+4HCl=$
$2CaCl_2+2H_2O+2O_2$ □

14. Phosphoric acid is H_3PO_4. Calcium Phosphate will have the formula:
1. $CaPO_4$ □
2. Ca_2PO_4 □
3. $Ca_3(PO_4)_2$ □
4. $Ca(PO_4)_2$ □

15. The chemical formula for Potassium Sulphate is:
1. KSO_4 □
2. K_2SO_4 □
3. $K(SO_4)_2$ □
4. $K(SO_3)_2$ □

16. The chemical formula for Ammonium Dichromate is:
1. $NH_4Cr_2O_7$ □
2. $NH_4(Cr_2O_7)_2$ □
3. $(NH_4)_2Cr_2O_7$ □
4. $(NH_3)_2CrO_4$ □

17. The common name for Na_2CO_3 is:
1. Washing Soda □
2. Caustic Soda □
3. Soda Bicarb □
4. Common Salt □

18. When bromine from sea water is absorbed in sodium carbonate one of the products formed has the formula $NaBrO_3$. Its chemical name is:
1. Sodium bromate □
2. Sodium bromite □
3. Sodium hypobromite □
4. Sodium perbromate □

19. The common name for KOH is:
1. Caustic Soda □
2. Caustic Potash □
3. Caustic Lotion □
4. Lime water □

20. The chemical name of H_3PO_4 is:
1. Pyrophosphoric Acid □
2. Meta-Phosphoric Acid □
3. Ortho-Phosphoric Acid □
4. Phosphorus Acid □

21. Which of the following is the correct formula for chromium sulphate?
1. $CrSO_4$ □
2. $Cr(SO_4)_2$ □
3. $Cr_2(SO_4)_3$ □
4. $Cr_3(SO_4)_2$ □

22. The number of electrons in the outermost shell of hologens is:
1. One □
2. Two □
3. Four □
4. Seven □

23. The chemical name of $Na_2S_2O_3$ is:
1. Sodium Sulphate □
2. Sodium Bisulphate □
3. Sodium Thiosulphate □
4. Sodium Thiosulphite □

24. K_2SO_4, $Al_2(SO_4)_3\ 24H_2O$ is a
1. Double Salt □
2. Complex Salt □
3. Simple Salt □
4. Acid Salt □

25. The formula of phosphoric acid is H_3PO_4. The formula of the metal forming a phosphate of the formula MCl_2 will be:
1. MPO_4 □
2. M_2PO_4 □
3. $M(PO_4)_2$ □
4. $M_3(PO_4)_2$ □

26. When a correctly written chemical equation is balanced:
1. The number of atoms of each kind on each side should be equal □

2. All molecules are diatomic ☐
3. All substances are in the same physical state ☐
4. The sum of coefficients on both sides is the same ☐

27. The number of molecules present in one gram molecule of a gas is known as:
1. The molecular weight ☐
2. The atmonic number ☐
3. Vapour density ☐
4. Avogadro's number ☐

28. The chemical name of NO is:
1. Nitrous Oxide ☐
2. Nitric Oxide ☐
3. Nitrogen Peroxide ☐
4. Nitrogen Oxide ☐

29. The formula of hypochlorus acid is HClO. The formula of the hypochlorite of a divalent metal M is:
1. MClO ☐
2. $M(ClO)_2$ ☐
3. M_2ClO_2 ☐
4. None of these ☐

30. The Sodium Chloride crystal is made up of:
1. NaCl molecules ☐
2. Na and Cl atoms ☐
3. Na^+ and Cl^- ions ☐
4. Two Na atoms for each Cl_2 molecules ☐

Answers

1. (3), 2. (3), 3. (2), 4. (3), 5. (3), 6. (4), 7. (1), 8. (2),
9. (4), 10. (3), 11. (2), 12. (2), 13. (2), 14. (3), 15. (2), 16. (3),
17. (1), 18. (1), 19. (2), 20. (3), 21. (3), 22. (4), 23. (4), 24. (1),
25. (4), 26. (1), 27. (4), 28. (1), 29. (2), 30. (3).

CHEMISTRY TEST NO. 2 (LAWS, PROPERTIES & APPLICATIONS)*

Max. Marks—30

Time: 40 mts.

Note: **Put a √ mark in the box opposite to the correct answer in the following questions.**

1. Charle's law deals with the relationship between:
1. Pressure and Volume ☐
2. Pressure and Temperature ☐
3. Volume and Temperature ☐
4. Mass and Volume ☐

2. Avogadro's hypothesis is helpful in finding the:
1. Vapour density ☐
2. Atomicity ☐
3. Valency ☐
4. Electronic configuration ☐

3. "One gram molecule of a gas at N.T.P. occupies 22.4 litres" may be derived from:
1. Dalton's Law ☐
2. Avogadro's Law ☐
3. Graham's Law ☐
4. Gas Equation ☐

4. Dulong and Petit's law helps in determining the:
1. Atomic weight ☐
2. Equivalent weight ☐
3. Molecular weight ☐
4. Atomic number ☐

5. NH_3 gas can be collected by the displacement of:

*Gupta, Sharwan Kumar, *ibid.*, p. 157.

1. Mercury ☐
2. Conc. H_2SO_4 ☐
3. Brine ☐
4. Water ☐

6. When the same electric current is passed through the solutions of different electrolytes in series, the amounts of elements deposited on the electrodes are in the ratio of their:
   1. Atomic numbers ☐
   2. Atomic weights ☐
   3. Specific gravities ☐
   4. Equivalent weights ☐
7. Graham's Law of diffusion is helpful in finding the:
   1. Equivalent weight of the gas ☐
   2. Molecular weight of the gas ☐
   3. Atomic weight ☐
   4. None of the above ☐
8. Hard water may be softened by passing it through:
   1. Sodium phosphate ☐
   2. Sodium silicate ☐
   3. Sodium hexa-meta phosphate ☐
   4. Sodium bicarbonate ☐
9. Avogadro's law correlates:
   1. Dalton's Atomic Theory and Gay Lussac's Law ☐
   2. Dalton's Atomic Theory and law of Multiple proportions ☐
   3. Dalton's Atomic Theory and Law of Constant proportions ☐
   4. Gay Lussac's Law and Law of constant proportions ☐
10. The favourable conditions for the maximum yield of ammonia by Haber's process are:
    1. High pressure, high temperature, high concentration of the reactants ☐
    2. Low temperature, low pressure, low concentration of the reactants ☐
    3. High pressure, low temperature, high concentration of reactants ☐
    4. High pressure, low temperature, low concentration of the reactants ☐
11. If t_1 and t_2 be the times for the diffusion of equal volumes of two gases, M_1 and M_2 be their molecular weights, d_1 and d_2 be their densities, and r_1 and r_2 be their rates of diffusion, then t_1/t_2 is equal to:
    1. r_1/r_2 ☐
    2. $\sqrt{d_2/d_1}$ ☐
    3. $\sqrt{M_1/M_2}$ ☐
    4. M_1/M_2 ☐
12. Hydrogen may directly combine with:
    1. Magnesium ☐
    2. Zinc ☐
    3. Copper ☐
    4. Calcium ☐
13. Chemically, rust of iron is:
    1. Iron oxide ☐
    2. A mixture of ferric oxide with a little ferric hydroxide ☐
    3. Hydrated ferrous oxide ☐
    4. Ferroso-ferric oxide ☐
14. A gas which produces brown fumes in air is:
    1. CO ☐
    2. Cl_2 ☐
    3. N_2O ☐
    4. NO ☐

15. The conversion of lead oxide, PbO to lead nitrate, $Pb(NO_3)_2$, involves:
    1. Reduction ☐
    2. Oxidation ☐
    3. Both oxidation and reduction ☐
    4. Neither oxidation nor reduction ☐
16. When Fe^{2+} changes to Fe^{3+} in a reaction:
    1. It loses an electron ☐
    2. It gains electron ☐
    3. It gains a proton ☐
    4. It loses a proton ☐
17. The weights of two elements A and B combining with one another are in the proportions of their:
    1. Atomic Weights ☐
    2. Equivalent Weights ☐
    3. Equivalent Weights or small multiples of them ☐
    4. Atomic Volumes ☐
18. Which of the following properities of elements is a whole number?
    1. Atomic Weight ☐
    2. Atomic Radius ☐
    3. Atomic Volume ☐
    4. Atomic Number ☐
19. Which is the best reducing agent?
    1. F^- ☐
    2. Cl^- ☐
    3. Br^- ☐
    4. I^- ☐
20. To test whether a given clear liquid is water, the best method wouid be:
    1. Examine it under a microscope ☐
    2. Smell it ☐
    3. Add anhydrous copper sulphate and look for a colour change ☐
    4. Heat it and find if it evaporates completely without leaving a residue ☐
21. Hydrogen may be liberated from ammonia by passing it over heated:
    1. Silver ☐
    2. Sodium ☐
    3. Copper ☐
    4. Carbon ☐
22. When nitric acid reacts with metals, nitrogen dioxide is usually evolved if the acid is:
    1. Dilute ☐
    2. Very dilute ☐
    3. Moderately strong ☐
    4. Concentrated ☐
23. Crude sulphur is purified by:
    1. Distillation ☐
    2. Sublimation ☐
    3. Liquefaction followed by distillation ☐
    4. Electrolysis ☐
24. Bone charcoal is used for decolourising sugar because it:
    1. Oxidises colouring matter ☐
    2. Absorbs colouring matter ☐
    3. Reduces colouring matter ☐
    4. Decolouring matter ☐
25. In the Haber's process for the manufacture of ammonia:
    1. Finely divided iron is used as catalyst ☐
    2. Finely divided molybdenum is used as catalyst ☐
    3. Finely divided nickel is used as catalyst ☐
    4. No catalyst is necessary ☐

26. Ammonia may be dried by passing it through:
   1. Conc. H_2SO_4 ☐
   2. Slaked lime ☐
   3. Anhydrous $CaCl_2$ ☐
   4. Quicklime ☐

27. When zinc pieces are added to an acidified solution of potassium permanganate, the solution becomes colourless. This is due to the:
   1. Bleaching of the solution by hydrogen ☐
   2. Reduction of potassium permanganate, by nacent hydrogen ☐
   3. Decomposition of pot. permanganate by zinc ☐
   4. Catalytic action of zinc ☐

28. Which one of the following statements is true for both strongly acidic and strongly basic solutions:
   1. The solution is a good conductor of electricity ☐
   2. The solution reacts with metals to liberate H_2 ☐
   3. The sol tion possesses excellent solvent properties ☐
   4. The solution does not conduct electricity ☐

29. When sulphur dioxide is passed through bromine water:
   1. It becomes colourless ☐
   2. No change is observed ☐
   3. It becomes red ☐
   4. Bromine vapours are evolved ☐

30. Carbon monoxide may be freed from carbon dioxide by passing the gas through:
   1. Ammonical cuprous chloride ☐
   2. Water ☐
   3. Solution of caustic potash ☐
   4. Conc. sulphuric acid ☐

Answers

1. (3), 2. (2), 3. (3), 4. (1), 5. (1), 6. (4), 7. (2), 8. (3),
9. (1), 10. (3), 11. (3), 12. (4), 13. (2), 14. (4), 15. (4), 16. (1),
17. (2), 18. (4), 19. (4), 20. (3), 21. (2), 22. (4), 23. (3), 24. (2),
25. (1), 26. (4), 27. (2), 28. (1), 29. (1), 30. (3).

CHEMISTRY TEST NO. 3 [NUMERICALS]*

Time—40 mts. Max. Marks—34

Note: **Put a √ mark in the box opposite to the correct answer in the following questions.**

1. A compound of empirical formula C_2H_5O has a molecular weight of 90. Its molecular formula is:
   1. CH_2O ☐
   2. $C_4H_{10}O_2$ ☐
   3. $C_3H_6O_3$ ☐
   4. $C_4H_5O_2$ ☐

*Gupta, Sharwan Kumar, *ibid.*, p. 159.

2. The molecular weight of a gas is 44.8 gms. What volume will 2 gms. of the gas occupy at 0°C and 1 atmosphere pressure?
   1. 0.5 litre □
   2. 1 litre □
   3. 2 litres □
   4. 11.2 litres □
3. An organic compound is found to contain C=54.5%, O=36.4% and H=9.1% by weight. Its empirical formula is:
   1. CHO_2 □
   2. CH_2O □
   3. C_2H_4O □
   4. C_2H_4O □
4. The molecular weight of sulphuric acid is 98 and its basicity is 2. Then the equivalent weight of the sulphuric acid is:
   1. 98 □
   2. 196 □
   3. 49 □
   4. 147 □
5. At N.T.P., 5.6 litres of a gas weighs 60 g. The vapour density of the gas is:
   1. 60 □
   2. 120 □
   3. 30 □
   4. 2.0 □
6. The chemical composition of a compound is C=40%, H=6.6% and O=53.4%. Its empirical formula is:
   1. CH O □
   2. CH_2O □
   3. CHO_2 □
   4. CH_2O_3 □
7. 90 parts by weight of anhydrous oxalic acid combines with 16 parts by weight of oxygen according to equation.

$$\begin{array}{l} COOH \\ \;\;| \\ COOH \end{array} + O \rightarrow 2CO_2 + H_2O$$

The equivalent weight of anhydrous oxalic acid is:
   1. 90 □
   2. 45 □
   3. 180 □
   4. 30 □
8. One litre of a gas collected at S.T.P. will occupy at 2 atmosphere pressure at 27°C.
   1. $1 \times \frac{2}{1} \times \frac{300}{273}$ litres □
   2. $1 \times \frac{1}{2} \times \frac{300}{273}$ litres □
   3. $1 \times \frac{2}{1} \times \frac{271}{273}$ litres □
   4. $1 \times \frac{1}{2} \times \frac{273}{300}$ litres □
9. Two litres of a gas are maintained at 25°C and 2 atmospheric pressure. If the pressure is doubled and absolute temperature is halved gas will now occupy:
   1. 2.0 litres □
   2. 4.0 litres □
   3. 0.5 litre □
   4. 1.0 litre □
10. The volume of oxygen at N.T.P. required for the complete combustion of 2 litres of carbon monoxide at N.T.P. is:
    1. $\frac{1}{2}$ litre □
    2. 1 litre □
    3. 2 litres □
    4. 4 litres □
11. One litre of nitrogen at N.T.P. will weigh:
    1. 1.25 g. □
    2. 12.5 g. □
    3. 11.2 g. □
    4. 0.625 g. □
12. The density of the gas A is twice that of gas B. If the molecular weight of gas A is M, the molecular weight of gas B is:

1. M
2. 2M
3. M/2
4. 4M

13. The weight of 4.0 litres of a gas at N.T.P. is equal to 2 gms. The molecular weight of the gas is:
1. 22.4
2. 11.2
3. 44.8
4. 5.6

14. Using Dulong and Petit's law, the valency of a metal of equivalent weight 50 and specific that 0.32 is:
1. 2
2. 3
3. 4
4. 5

15. 73 parts by weight of hydrochloric acid neutralizes 106 parts by weight of sodium carbonate. Then the equivalent weight of the acid is:
1. 73
2. 53
3. 106
4. 146

16. The relative rate of diffusion of a gas as compared to that of carbon dioxide is 266: 213. The molecular weight of the gas is:
1. 14
2. 42
3. 28
4. 7

17. What volume of a gas with density 16 will diffuse in the same time as 200 c.c. of hydrogen with density one diffuses through the same aperture?
1. 800 c.c.
2. 500 c.c.
3. 50 c.c.
4. 100 c.c.

18. The molecular wt. of gas is 22.4. What will be the volume of 2 grams of this gas at 0°C and 1 atmosphere pressure:
1. 1 litre
2. 2 litres
3. 11.2 litres
4. 0.5 litre

19. On vaporisation, W gms. of a substance occupied 11.2 litres. Its molecular weight is:
1. W
2. 2 W
3. 11.2 W
4. W/11.2

20. The weight of hydrochloric acid (H Cl) required for complete decomposition of 50 grams of calcium carbonate ($CaCO_3$) is
1. 68.5 gms.
2. 36.5 gms.
3. 26.0 gms.
4. 46.5 gms.

21. What volume of a gas with density 16 will diffuse in the same time as 200 c.c. of hydrogen with density 1 diffuses through the same aperture?
1. 100 c.c.
2. 500 c.c.
3. 50 c.c.
4. 400 c.c.

22. Certain volume of a gas X of density 16 diffuses out in 64 seconds. Under similar conditions how long will it take an equal volume of gas Y of density 25 to diffuse?
1. 25 Secs
2. 64 Secs

3. 80 Secs ☐
4. 40 Secs ☐

23. 316 parts by weight of an oxidizing agent ($KMnO_4$) gives out 80 parts of oxygen. The equivalent weight of $KMnO_4$ is:
1. 31.6 ☐
2. 35.5 ☐
3. 158 ☐
4. 36.5 ☐

24. 25 c.c. of N/5 solution of H/Cl exactly neutralized 20 c.c. of a solution of a base containing 4.8 gms. per litre of the base. Find the equivalent weight of the base:
1. 38.4 ☐
2. 19.2 ☐
3. 9.6 ☐
4, 24.0 ☐

25. 1 litre of 18 molar sulphuric acid has been diluted to 100 litres. The normality of the resulting solution is:
1. 09 N ☐
2. 3.18 N ☐
3. 1800 N ☐
4. 1.8 N ☐

26. 48 c.c. of N/7 Na OH solution neutralized 24 c.c. of H_2SO_4 solution. The strength of the acid solution is:
1. 14 gms. per litre ☐
2. 28 gms. per litre ☐
3. 49 gms. per litre ☐
4. 98 gms. per litre ☐

27. 98 parts by weight of sulphuric acid neutralizes 100 parts by weight of calcium carbonate. The equivalent weight of calcium carbonate is:
1. 47 ☐
2. 100 ☐
3. 50 ☐
4. 98 ☐

28. The normality of the solution containing 2.4 grams of sulphuric acid in 250 c.c. is:
1. 0.156 ☐
2. 0.250 ☐
3. 0.196 ☐
4. 0.240 ☐

29. 10 g. of hydrofluoric acid gas occupies 5.60 litres of volume at N.T.P. The empirical formula of the gas is HF. The molecular formula in the gaseous state will be:
1. HF ☐
2. H_2F_2 ☐
3. H_3F_3 ☐
4. H_4F_4 ☐

30. The oxide of an element contains 33.33% of the element. The equivalent weight of the element is:
1. 16 ☐
2. 8 ☐
3. 32 ☐
4. 4 ☐

31. The chloride of a divalent element contains 35.5 per cent chlorine. Find out the atomic weight of the element:
1. 129.0 ☐
2. 119.0 ☐
3. 71.0 ☐
4. 139.0 ☐

32. Zinc and sulphuric acid react together to form hydrogen. The weight of sulphuric acid required to reduce completely 79.5 gms. of copper oxide to copper?
1. 98 gms. ☐
2. 49 gms. ☐
3. 79.5 gms. ☐
4. 159.0 gms. ☐

33. 2.70 grams of metal are treated with excess of sulphuric acid. The volume of hydrogen collected at N.T.P. $=1000$ c.c. The equivalent weight of the metal is:
1. 27.0 □
2. 27.24 □
3. 32.00 □
4. 30.24 □

34. The equivalent weight of an oxide of element is 4. The same forms chloride whose vapour density is 59.25. Then the valency of the element is:
1. 2 □
2. 3 □
3. 4 □
4. 5 □

Answers

1. (2), 2. (2), 3. (3), 4. (4), 5. (2), 6. (2), 7. (2), 8. (1), 9. (3), 10. (2), 11. (1), 12. (3), 13. (2), 14. (3), 15. (2), 16. (3), 17. (3), 18. (2), 19. (2), 20. (2), 21. (3), 22. (3), 23. (1), 24, (2), 25. (1), 26. (1), 27. (3), 28. (3), 29. (2), 30. (4), 31. (1), 32. (1). 33. (4), 34. (2).

12

CONCEPT FORMATION IN TEACHING PHYSICAL SCIENCES

Words, symbols, and their interrelationships and meanings are concepts. The degree to which people will attach the same meaning for any given concept will vary. The individual's experience will influence the kind of meaning assigned to a given word or other type of symbol. In explaining concepts, Thorndike writes:

> Meanings are in persons' minds, not in words, and when we say that a word has or possesses such and such meanings, we are really saying that it has evoked, or caused, these meanings. Until it gets into a mind, a word is only puffs of air or streaks of ink. What a word, sentence or other expression means to a hearer or reader is mainly what it makes him think or feel to do as a fairly direct consequence of hearing or seeing it, and, more narrowly, what it makes him think or think of, as the direct and almost immediate consequence of hearing or seeing it."[1]

In teaching science to children, many new and technical words are introduced which have little or no meaning. It is well to utilize pupil experiences in the out of school as a basis—for assigning meaning or extending meaning in order that new concepts may be formulated. Learning activities and applications of science concepts constitute important ways of helping children to understand science. Perhaps one of the most common errors is the assumption that the teacher may not be able to determine any concept already possessed by the learner. In her doctoral dissertation, Nelson states that: "Many concepts and scientific principles were stated by the children with evident pride in their knowledge before any instruction in the two areas of Light and Sound had been begun."[2]

Nelson reported on a number of factors that are significant in teaching science concepts. Children are willing to change their ideas after

1. Thorndike, Edward. L., The Psychology of semantics, *American Journal of Psychology*, 59:613, Oct. 1946.
2. Nelson, Pearl, A., Concepts light and sound in the intermediate grades, *Science Education*, 44:143, March 1960.

instructions. This is a result of problem solving activity and suggests that children should be given a freer atmosphere in which to verbalize. Verbalization reveals the depth of science information and shows how pupils think. Evaluation, suspended judgement, an atmosphere of acceptance during discussion, and verbalization are all related to problem solving activities and science concept formation.

"Concepts are not always arrived at directly. Frequently, much thought is involved in their development. It is important for teachers to realize and to appreciate how much children think about their experiences and work to integrate them into satisfactory understandings. Sometimes long periods of time elapse between the original experiences, the development of concepts, and the application of the concepts."[3]

Concepts change for each individual as he gains greater experiences and understanding. It should not be assumed that all children at the same level of learning will formulate identical concepts of the same item. Each individual will interpret natural phenomena in terms of his own experience. A pupil's environment and his prejudices will affect concept formation.

Concept formation should be evaluated by pupil's ability to transfer and apply knowledge and experience in new problems. It is for this reason that problem solving skills are excellent means for teaching science concepts, attitudes, and solutions to problems. Blackwood writes, "In a very real sense the product of scientific inquiry is a body of clarified concepts."[4]

Direct experiences are essential in concept formation. Pupils in the lower grades are more concerned with what happened in observing individual experiments and older children seek the answer to the question "why". Educationists compared pupils in grades 1 and 3 as they played with magnets and other articles. Pupil observation during individual experimentation played vital role in formulation concepts. This was demonstrated during the play with the magnets and can be observed when children have direct experiences.

Although not many studies are available that show the relationship between understanding science concepts and intelligence, reading ability, socio-economic status, and sex, Kearney believes that there is a definite relationship.[5] A child who has a number of books, especially

3. Garone, John E., Acquiring Knowlege and attaining understanding of children's scientific concept development, *Science Education*, 44:106, March 1960.
4. Blackwood, Paul, E., A Welcome and a challenge. A welcome and a challenge. *Science Education*, 45:25, Feb. 1961.
5. Kearney, Ruth, A., Science Concepts of Sixth Grades. Abstract. In Johnson, Philip, G., Science Edu. Research Studies—1952, *Science Education*, 38:8, Feb. 1954.

science reading materials, *in the home as well as in the school, will* probably understand science concepts more readily. The socio-economic status may be a factor in determining whether the parents have the financial means and interest to buy such books for the children at home. Reading ability will also have a profound effect on intelligence and the ultimate ability to understand and modify science concepts.

EXAMPLES:

I. *What are Molecules?*[6]

Concepts

1. All matter is composed of tiny particles called molecules.
2. Molecules are too small to be seen with the naked eye.
3. Sometimes matter is made up of only one kind of molecule and scientists call this matter an element.
4. Sometimes matter is made up of more than one kind of molecule and scientists call this matter compounds.
5. Molecules are always in motion.

Materials

Piece of coal or charcoal paper towel,
Ether, alcohol, or perfume
Hammer
Shallow dish

Discussion

1. Have you ever heard of molecules?
2. What do you know about molecules?

Processes	*Pupil Discovery Activity*

Part—I

1. Obtain a piece of coal or charcoal (mostly Carbon), a hammer, and a paper towel. Place the coal or charcoal on the paper towel and pound it with the hammer until you see fine coal dust.

Observing:	How does the pounding change the coal?
Hypothesizing:	Do you think you have made a new substance? Why do you think as you do?
Hypothesizing:	What would you have to do to change the coal to a new meterial?
Hypothesizing:	If you keep pounding the dust into smaller and smaller pieces, what will you ultimately end up with?

6. Carin, Arthur, A., Sund Robert B., *Teaching Science through Discovery*, Charles E. Merrill Publishing Co., Columbus, Ohio.

Teacher's Note: Explain that all elements are composed of tiny invisible particles. These tiny particles are called molecules.

Do not convey to the children the idea that the dust from the coal is a single molecule. Molecules are too small to be seen by the naked eye and must be seen through a microscope. The dust particles are aggregation or collections of molecules.

Part—II

1. Teacher will pour a liquid (Ether or alcohol) into a dish at the front of the classroom.
2. Raise your hand when you first notice an odour.

Observing: From the sequence or order in which hands are raised, can you find the direction in which the small travelled?

Inferring: Why this happened?
What are water molecules and how do they affect each other?

Concepts

1. The deeper the water, the greater the pressure.
2. Water has cohesive force.
3. A force is defined as push or pull on an object.
4. Molecules of the same substance tend to stick each other because they are attracted by an invisible force.
5. Each molecule of the substance pulls other atoms to it.
6. The force of attraction between molecules of the same kind is called cohesive force.

II. What causes the molecules of a liquid to move?

Concepts

1. The molecules in liquid are constantly moving in a random pattern or Brownian movement.
2. This motion is caused by heat.

Teacher's Note: A reasonable assumption is that a little of the liquid evaporates and escapes into the air. It may be pointed out that the liquid must have been made up of tiny invisible particles and that the tiny particles called molecules must be in motion.

Designing an Investigation

3. Can you think of some simple experiment to test the idea that molecules in liquids evaporate or go into the air at different rates?

Teacher's Note: If the children cannot come up with an experiment then suggest they smear ether, alcohol, water, and oil on the

chalkboard. Solicit hypotheses as to which liquids will disappear or evaporate at which rates and possibly why.

4. Test your experiment.

Applying

5. How can you speed up or slow down the liquid molecules' disappearing or evaporating?

Open-Ended Questions

1. Why do you think clothes dry faster on sunny days? Windy days?
2. Which would you smell first if a small dish were pleased in front of your classroom and you were in the back of the room: Vinegar, ether, alcohol, or perfume? Why do you think as you do?

III. What are Atoms?

Concepts

1. Changing the size of an object does not change its physical characteristics.
2. All elements are composed of atoms.
3. An atom is very small.
4. Atoms are grouped in various ways to make molecules.
5. An atom is made up of electrons, protons and neutrons.
6. Negatively charged bodies have more electrons than protons.
7. Electrons are negatively charged particles.
8. Protons are positively charged particles.
9. Neutrons have neither a positive nor a negative charge.

Materials

1. Wooden blocks
2. Two wire clothes hangers
3. Picture of Solar systems
4. Styrofoam ball about the size of a Ping-Pong ball
5. Six rubber jack balls or styrofoam balls that size
6. Wire cutters

Discussion

What do you know about atoms?
What do you think an element is?
What do you think an electron is?
What do you think protons and neutrons are?
How big do you think an atom is?
What do you know about molecules?

Teacher's Note: Atoms are very small. The thickness of a human hair probably contains at least 500,000 atoms. An atom consists of

fundamental particles called electrons, protons, and neutrons. Protons and neutrons are found in the centre (or nucleus) of the atom while electrons revolve around the nucleus. The revolving electrons are grouped together in shells or orbits around the nucleus. The neutron has nearly the same mass as the proton and, as could be guessed from its name, is electrically neutral and carries no charge. The nucleus contains most of the weight or matter and is the most important part of the atom. Therefore, the nucleus is also the heaviest part of an atom. When an atom is neutral, it has an equal number of electrons and protons. If there are more electrons, the atom is negatively charged. All atoms have a tendency to balance the number of electrons and protons by drawning electrons or giving off extra ones and in the process become neutral.

Processcs

Pupil Discovery Activity

1. Obtain a wire clothes hanger, a block of wood, some plasticine or Styrofoam balls, and six rubber jack balls. Assemble the materials.

Inferring

2. In what ways is your model different from a real atom?

Teacher's Note: All the particles in the atom would be in motion. The orbits the electrons follow would not be so definite as those formed by the wire in the student model.

Hypothesizing

3. How could you improve the model shown in the diagram?
4. Look at a picture of our Solar system.

Comparing: What do you notice about the Solar system that can be said about an atom?

5. In what ways is the Solar system different from an atom? How is it similar?

13

CREATIVITY IN PHYSICAL SCIENCES

Definition of Creativity

Many psychologists and scientists have endeavoured to define, characterize, and develop creativity, all with various degrees of success. A leader in this endeavour has been Dr Paul Torrance. He says:

"I have chosen to define creative thinking as the process of sensing gaps or disturbing missing elements; forming ideas or hypotheses, and communicating the results, possibly modifying and restating the hypotheses."[1]

Creativity is generally thought of in two ways. Some believe it should be restricted to the production of a new entity or idea never before known to man. Others have a more inclusive definition including all productive endeavours unique to the individual. This latter view is the more useful for teachers trying to develop creative ability and helping individuals to self-actualise.*

Creative Abilities

Psychological research has revealed that creative abilities may be separated into the following categories:

1. Fluency	Proposes many similar ideas for a problem.
2. Flexibility	Produces many different classes of ideas for a problem.
3. Originality	Gives uniquely different responses from other people.
4. Elaboration	States many details related to the creative response indicating how it

1. Paul Torrance, *Guiding Creative Talent*, Englewood Cliffs, N.J., Prentice-Hall, 1962.

* Self-actualization. Individuals who are active, dedicated to something they believe in and very much involved in their commitments. They have the will to do and are using to the best of their ability their maximum human potential.

	may be constructed and implemented.
5. Sensitivity	Generates many problems in response to a situation.

Characteristics of Creative Individuals

Creative individuals vary in motivational, intellectual, and personality traits. Individuals with creative potential can be most easily recognized by the following characteristics.

1. *Curiosity*. This probably is one of the easiest signs by which a teacher can discover creative individuals.
2. Resourcefulness.
3. Desire to discover.
4. Preference for difficult tasks.
5. Enjoyment in solving problems.
6. Drive and dedication to work.
7. Flexible thinking.
8. Responsiveness to questions and habit of giving more answers to questions than do most students.
9. Ability to synthesize and see new implications.
10. Pronounced spirit of inquiry.
11. Breadth of reading background.

In addition to the above, the creatively talented have a marked ability to form abstractions, analyze, and synthesize information. They demonstrate persistent and sustained concentration and are usually sensitive and individualistic. Given freedom as well as direction creative students often surprise the instructor with their capabilities and interests.

The Stimulating, Creative Class Environment

Jack R. Gibbs[2], in working with various types of business, industries, and government agencies has found that creativity within the organization can be enhanced by increasing trust, free communication, self-determination, and decreasing control. How this might be done adapting Gibb's ideas for teaching is briefly outlined below.

Enhancing the Release of Creativity in Teaching

1. Develop high trust and reduce fear.	Indicate that you trust students to be productive, don't censor ideas, show less disapproval.
2. Encourage a free flow of communication.	Encourage creative work from all students. Strive to develop the idea

2. Jack R. Gibbs, "Managing for Creativity in the organization" in *Climate for Creativity*, ed. Calvin Taylor, Elmsford ,N.Y., Pergamon Press, 1972.

	that creativeness is an excellent way of behaving for all the members of your class. Be open and accept suggestions of students.
3. Allow self-determination of goals and self-assessment.	Consult students on what they are interested in and what it is they would like to do. You may present ideas but students are encouraged to accept or reject these and determine their own if they choose.
	Don't grade creative work. Encourage students to evaluate their work, e.g., how they may alter it in the future if they choose, etc. Don't make statements as to what is good or bad. Ask what other ideas arose from producing something creative. Ask how the works of the class differ. Encourage students to assess their work but not from the point of view it was they were trying to do, how they did it and what, if any thing, they might wish to change.
4. Control is not tight	Do not require conformity for your own and student behaviour, e.g., "Let's all make a pot". Encourage students to experiment with work and various learning procedures. Encourage and accept conflict and disagreement with your ideas. Give high priority to diversity and creativity over conformity.

Gibbs had found that creative managers and/or teachers are individuals who believe that people are self-motivated and responsible on their own, like to be creative if restraints are removed, work best when they set their goals, and manifest fantastic potential when allowed to do so.

Methods for Developing Creative Talent

To teach for creatively you will have to be creative in the methods and assignments you devise. Unfortunately, if you are a typical student or teacher you probably have not had many creative teachers after whom to model yourself. If you do encounter one, analyse what he does and endeavour to develop similar capabilities.

Other than providing the proper environment as suggested by Gibbs, there are certain specific teaching techniques which the teachers may use to stimulate creative teaching.

1. *Creative Questioning*

Creative questioning is basic to becoming a more creative teacher. Most of the following activities hinge on the teacher's asking questions requiring creative responses.

As has been pointed out earlier, there are different types of activities that have been defined as creative behaviours.

The questions asked should be based on the following types of creative abilities:

1. Fluency	It poses many similar ideas for one problem.
2. Flexibility	It generates many different classes of ideas for a problem outside of the usual category.
3. Originality	It gives unique or statistically uncommon responses from those proposed by other individuals.
4. Elaboration	It gives many details that spells out an idea.
5. Sensitivity	It senses problems from a situation.

2. *Creative Mental Processes*

A science teacher can develop creative questioning ability by giving creative mental exercise to his students by the following creative mental processes.

1. Originates problems.
2. Formulate hypotheses.
3. Design an investigation or experiment.
4. Infer.
5. Evaluate an experiment, research, scientific problem and tell how to modify and improve it.
6. Invent new uses for objects.
7. Develop new approaches.
8. Produce original art, literature, musical forms, etc., related to science.
9. Communicate uniquely, e.g., in reporting or summarizing.

3. *Creative Listening*

Students generally are taught in schools to listen mainly for the purpose of memorizing or recalling information. They should, however, also be encouraged to listen creatively. This means using listening to spark their imagination, i.e., listening to a film, radio, talk, recorded talks, music and then becoming involved in conveying its meaning in different ways or using it to leap in thought to new ideas.

4. *Creating Something. New Teaching Technique:*
   (1) *Topic for study is identified:* Teacher and/or students decide on some topic they wish to study, light, heat, mechanics, air pressure, etc.
   (2) *Determination of Background of Students: Phase:* Students are asked to tell what they know about a topic or describe a situation as they see it. These may be related to objects, concepts, personal and social problems.
   (3) *Defining a Problem or Task.*
   (4) Direct Analogy Phase.
   (5) Personal Analogy Phase.
   (6) Compressed Conflict Phase.
   (7) Relating Analogies Phase.
   (8) Individual students Creative Phase.
5. *Encourage your students* to prepare or become involved in any of the following:[3]
   (1) Constructing various types of learning puzzles and games in science.
   (2) Role-playing—as a scientist.
   (3) Suggesting how to improve some piece of equipment.
   (4) Using a commercially prepared film, filmstrip, or film loop in some innovative way.
   (5) Making a filmstrip, film loop or a series of Polaroid or other types of photographs of scientific interest.
   (6) Making a cassette recording conveying information related to class activities.
   (7) Making a scientific coat of arms, flag, model, or representation.
   (8) *Constructing a light symphony*: Use various transparent colour wheel made of cellophane and flash light through them to obtain the impression of changing light.
   (9) Recording on a pad near the bed when just before sleeping or awakening, a creative idea that comes into the mind. Act upon these ideas when completely awake later.
   (10) Compiling a list of problems or things that would be fun to investigate.
   (11) Publishing a creative science bulletin.
   (12) Drawing cartoons or a comic series related to what is being studied.

3. Carin Arthur, A., Sund Robert, B., *Teaching Science through Discovery*, 3rd ed. Charles E. Merrill Publishing Co.

(13) Making a booklet containing drawings, diagrams, photographs, etc., arranged in a creative manner.
(14) Constructing a diagram or taking a photograph of something in which there may be possibilities for individuals to perceive several different objects.
(15) Reading creatively. Use children as a springboard for new ideas. After reading something have them come up with a new idea, concept, or invention related to it.

Discovery-Inquiry procedures to stimulate creativity

Any of the inquiry approaches, as they encourage students to hypothesize, speculate, resolve problems, have creative components. Inquiry-oriented and student-centred activities, when enlisting students to originate a problems, hypothesize, design techniques of investigating, make discoveries, speculate, invent, form metaphors, etc., contribute considerably to the development of this most viable human talent.

Creative science teaching requires that teachers themselves continue to devise and become proficient in establishing a creative class environment. By so doing, they grow in becoming more fully functioning individuals.

Part II

CONTENT-ENRICHMENT PROGRAMME

14

THEORY OF RELATIVITY

Physicists had discovered that light (as in the case of sound) travels in waves and reasoned that light waves must also have a supporting medium. It is also a fact that light waves can pass through vacuum. So this medium, which is present even in vacuum is called 'Ether'. A number of scientists tried to detect the presence of the ether but in vain.

Another problem that puzzled physicists was the fact that the velocity of light was constant, 186,000 miles per second even if the source of light and the person making the measurement were moving with great speed.

Relative Motion

The concept of relative velocity is very important for understanding theory of relativity. Left and right are not absolute but relation, i.e., the object which is on the left of one may be on the right of other.

Ordinarily a stationary observer measures the velocities. If he is standing by the side of a road and sees two cars going fast in the same direction but travelling at different speeds. By timing he can correctly say that one car is travelling at say, 40 m.p.h. and other is travelling at 60 m.p.h. Scientifically speaking, it can be said that two cars move at 40 m.p.h. and 60 m.p.h. relative to the stationary observer. But if a passenger in the slower car finds the faster car and measures its velocity, he will find that the other car is travelling at 20 m.p.h. relative to him. And to a passenger in the faster car, the slower car is apparently moving backwards with a relative velocity of 20 m.p.h.

With this idea of relative velocity applied to the speed of light, scientists thought that the value obtained of the speed of light should depend upon the velocity of the observer. If he is at rest, the speed of light measured by him will be 186,000 miles per second and if he is moving, say in a spaceship at 80,000 miles per second and he is overtaken by a beam of light, he can be expected to measure the speed of light relative to himself as only 100,000 miles per second.

These two problems—the existence of 'Ether' and 'velocity of light' is dependent on the 'velocity of the observer' were solved, in 1905, by

Albert Einstein. He propounded his famous "Special Theory of Relativity". This theory is based on two assumptions called Axioms:

(*i*) The ether cannot be detected and the velocity of light is the same for all the observers;

(*ii*) That all motion is relative so that no observer is absolutely at rest.

The first axiom, that the velocity of light is constant, the same in all directions and for all observers and independent of the motion of the source of light or the motion of the receiver. The velocity of light is a fundamental unit, basic to several principles, including the equivalence of mass and energy as expressed in the familiar equation $E=mc^2$, where c, represents the velocity of light in free space.

Second, Einstein banished the concept of an absolute motion. Whether stated in one frame of reference or in any other, moving with uniform motion relative to the first, the laws of physics are the same. Motions had to be referred to some definite object or framework, such as the earth to the sun, or some other body in the universe. Motion is a relative, not an absolute, phenomenon to every observer.

Einstein said that there was no reason for the existence of an ether, hence no need for an ether to carry light.

The first axiom is confirmed from the study of stars. Certain stars, which appear as single points of light through naked eye, are seen through a telescope to be double. They consist of a pair of stars, held relatively close together by their attractive forces of gravity and orbiting round their common centre of gravity rather like a pair of skaters holding hands and circling a spot between them on the ice. At any instant, one star is moving towards earth and the other is moving away. After some time the first star recedes and, the other advances. But the time taken by light to reach earth from each star is the same, irrespective of the direction of motion of the star. So the velocity of light from each star is the same, i.e., 186,000 miles per second. This fact confirms that the velocity of light is completely independent of the speed of the light source.

It was again confirmed in 1887, by two American physicists, Albert A. Michelson and Edward Morley, who attempted to detect the presence of ether by measuring the velocity of light in two directions. Report of Michelson and Morley (Greatest of all Negative results) on the relative motion of the earth and the luminiferous ether.

The Michelson-Morley Experiment

An attempt to measure the velocity of the earth through Ether, by measuring the effect which such a velocity would have upon the velocity of light. No such motion of earth in relation to the ether was detected: a result of the greatest importance for the theory of relativity. The ether wind had no effect on the velocity of light whether it was travelling along or across it.

The second axiom, that no observer is absolutely at rest, is easier to accept. Let us assume that the pilot of a spaceship is travelling away from the earth along the earth's orbit. To an observer, on earth, the spaceship would appear to be moving away, at say, 100 miles per second. To the pilot of the spaceship, if he assumes himself stationary, the earth would appear to be moving away from him at 100 miles per second. Actually, the earth moves in its orbit round the sun at a speed of 19 miles per second. So, to a third observer in space, the Earth would appear to be moving at 19 miles per second and the spaceship at 119 miles per second relative to the sun. Therefore the velocities can only be calculated relative to the observer, and the Special Theory of Relativity says that no observer may assume that he is at rest.

Fitz Gerald and Hedrik Lorentz

The size of an object changes when the motion of the object is increased. In other words, stick which is measuring the distance between two fixed points shrinks in size of that stick which is moving through space along the line of its length at a very great velocity. The shrinkage—that is, the difference in length of the stick when at rest and when moving at high speed—depends upon the rate of stick's motion.

This theory was arrived at from certain mathematical considerations based on the electromagnetic properties of light proposed by Clark Maxwell.

This unorthodox explanation disturbed the orthodox physicists. No one, they argued, had ever seen a solid rod actually shrink, no matter how fast it was travelling in the direction of its length. That is true. But Fitz Gerald and Lorentz were not talking about the ordinary speeds with which practical engineers and every-day physicists dealt. They were not even talking of such speeds as those of bullets. Their calculations showed them a speed of even 300 miles an hour would produce a shrinkage of only one million millionth of 1 per cent—a shrinkage which, of course, our instruments could not detect.

Size and Mass near the Speed of Light

When they used a theoretical speed of about half the speed of light, or about 93,000 miles per second, however, the theoretical shrinkage amounted to 13.5 per cent. As this velocity was stepped up to 60 per cent of the speed of light, the shrinkage reached almost 50 per cent. At a velocity of 99 per cent of the speed of light, our measuring instruments would dwindle to about 14 per cent of their original length. Finally, according to their calculations, when the speed of the instrument reached about 186,300 miles per second, the shrinkage would reach a theoretical 100 per cent. In other words, at this colossal speed the material stick would disappear as a result of total shrinkage and would be completely converted into its equivalent amount of energy.

Actually, an object would never shrink to zero, since the faster the

motion the heavier it becomes, and the greater its mass, the more difficult it is for it to move faster. The velocity of light acts as a limiting value. Hence the measured length of an object would become zero, an inconceivable situation. Hence a speed exceeding that of light is physically impossible.

Let us now see what happens when an observer studies quantities such as length, mass and time, in a system that is moving relative to him. One of the predications of Special Theory of Relativity is that length of a fast moving object will appear to an outside observer to have contracted to a value smaller than that when the object was at rest relative to the same observer. Mathematically the new length is given by the equation:

$L_{new} = L_{old} \sqrt{l - v^2/c^2}$, where v is the velocity of the moving object; and c is the velocity of light.

A spaceship of length 50 feet travelling at a speed of 100,000 miles per second relative to an observer appears to him of length 42 feet. He further finds that as the spaceship travels faster and faster, its length appears to be shorter and shorter. When it is travelling nearly at the speed of light, it will become infinitely small. The decrease in length with increase of velocity is one of the reasons for the velocity of light to be constant.

A second prediction of special theory of relativity is that the mass of a moving body appears to be increasing to the stationary observer, and is given by

$$M_{new} = \frac{M_{old}}{\sqrt{l - v^2/c^2}}$$

Suppose a spaceship has a mass of five tons when it is at rest. To an outside observer, its mass would increase by a ton when it is travelling at 100,000 miles per second. It becomes more and more massive as its speed approaches the velocity of light and at the speed of light its mass would be infinite.

Another prediction made by Special Theory of Relativity is that the time will be affected by velocity and will pass more study on a fast moving object. The extent of slowing, the so-called timedilation, is given by the equation:

$$T_{new} = \frac{T_{old}}{\sqrt{l - v^2/c^2}}$$

The time expansion is given by the same factor $\sqrt{\frac{l - v^2}{c^2}}$ as the space contraction, with the difference that here you use it not as a multiplier but as a divisor; if one moves so fast that the lengths are reduced to one half, the time intervals become twice as long. The hypothetical spaceship has already struck by 8 feet and more massive

by about a ton because it is moving at 100,000 miles per second. In such a spaceship, time will pass at about four-fifth of the rate at which it passes for an outside stationary observer.

Consider an interesting puzzle: a forty-year old man falls in love with a sixteen-year old girl. They feel that their age difference makes the marriage out of question. The man synchronising his clock with that of girl goes on a long space journey, travelling close to the speed of light (0.999c). He returns when his clock reads one year and he reads the clock of his beloved to his great surprise in her clock 22.3 years have passed. This in turn means that the man is 41 years old and the girl is $22.3 + 16 = 38.3$ years old. So the age difference barrier is overcome and they marry.

One of the most important results derived from the Special Theory, though strictly not part of it, is the equivalence of mass and energy. Since the mass of an object increases with velocity, its energy much increase. Every mass m has an associated energy E. The exact equivalence is given by Einstein $E = mc^2$, where c is the velocity of light. This equation allows us to calculate the total amount of energy available in a given mass. For example, one gram of mass is equivalent to about one thousand million billion ergs of energy, which in the form of electricity would be enough to serve a large city for several months.

What would happen to a spaceship approaching the speed of light? According to Einstein's special theory, it would shrink, yet its mass would increase and its clocks would show down.

15

RADIO-ACTIVITY

Natural Radio-Activity—Bacquerel Rays

Bacquerel found that a preparation of Potassium and Uranium Sulphate, when exposed to bright sunlight, affected the photographic plates, wrapped in black paper. He later showed that crystals of Potassium Uranyl Sulphtate emit continuously, without previous exposure to sunlight, a radiation which not only affects the photographic plates, but can also discharge charged gold leaf electroscope by producing ionisation. These radiations were called Bacquerel Rays and the phenomena came to be known as Radio-activity.

Pierre and Madam Curie, husband and wife, then tried to discover some substances which could give out Bacquerel Rays. They found that radio-activity was exhibited by all compounds of uranium and the amount of activity, as measured by their ionising power, was proportional to the uranium contents in the specimen. They found that a naturally occurring ore, *pitch blende* showed four times more radio-activity than its uranium contents warranted and inferred the presence of some substance much more radio-active than uranium.

In December, 1895, the Curies discovered an important radio-active element, which they named Radium. Radium was found to be a million times more radio-active than an equal mass of uranium. They succeeded in isolating only 2 milligrams of radium from 30 tons of pitch blende.

Many more radio-active substances were discovered in quick succession. Schmidt and Curie in 1898 showed that adjacent element before uranium, namely thorium exhibited radio-active properties. In due course Actinium was discovered whose radio-activity was found to die out in a few seconds.

The phenomenon of radio-activity is exhibited by elements of high atomic weight whose nuclei are rather unstable and break up their own accord into similar elements giving out some radiation. The process is spontaneous in the sense that it can neither be started, stopped, accelerated nor retarded under any physical circumstance.

The new elements formed during radio-active changes, may themselves show pronounced radio-activity and break up into still simpler atoms and emanations.

The radio-active substances possess three outstanding properties:

(*i*) They affect a photographic plate like light or X-rays;

(*ii*) They penetrate through matter, the thickness depending upon the nature of radiations and source;

(*iii*) They ionise the gas through which they pass.

The property of ionisation leads to many physical and chemical changes, e.g., water is decomposed when X-rays are passed through it; soda-glass exposed to these radiations is coloured deep violet and after continued exposure even black. Rutherford, in 1902, attempted to determine the nature of these radiations. He found that one of the radiations was readily absorbed by even a thick sheet of paper. These were called α-rays. The other radiation was much more penetrating and could pass through 5 mm. of aluminium or 1 mm. of lead, which he named the β-rays. Later one more penetrating radiation was discovered which could pass through several cms. of iron (30 cms.) and was called γ-rays. All these radiations emanate from the nucleus of radio-active atom so that the phenomenon of radio-activity is essentially a nuclear phenomenon. It is, however, not necessary that all three types of radiations be given out by every radio-active substance.

α-*Rays*

These are the heavy particles emitted by radio-active substances. There mass is four times that of the hydrogen nucleus and the same as the mass of the helium nucleus (Mass of an α-particle $= 6.644 \times 10^{-24}$ (gm.). They are now known to be helium nuclei.

Each of these particles carries twice the amount of positive charge as carried by an electron. (The charge on an α-particle $= 2 \times 1.602 \times 10^{-19}$ Coulombs $= 2 \times 4.802 \times 10^{-10}$ e.s.u.). This is the same as the charge on the helium nucleus.

α-particles have great ionising power, 100 times that to β-rays and 10,000 times that due to γ-rays. The penetrating power of α-rays, however, is much less. about 1/100 of the β-rays and 1/10000 of that of γ-rays. A thickness of 0.0005 cm. of Aluminium foil reduces the ionising power to half and a thick sheet of paper can stop them.

They produce fluorescence when they fall on certain substances, e.g., diamond fluorescence with blue light and zinc sulphide screen gives tiny specks, called scintillations.

β-*Rays*

The β-rays are negatively charged particles moving with a very high velocity between 0.36 to 0.98 times the velocity of light. The β-rays are about 100 times more penetrating than α-rays and 1/100 times as much as γ-rays. The ionising power of β-rays is 100 times that of γ-rays but only 1/100 times that of the α-rays.

The specific charge $\frac{e}{m}$ for the β-rays wac determined to be the same as for the electrons. They are more readily scattered by atomic nuclei than α-rays on account of their relatively smaller mass.

γ-Rays

They are very short electromagnetic waves, shorter than even the hardest X-rays. The wavelength is of the order 10^{-10} cm.

They eject β-rays from matter on which they fall. The velocity of projection of the secondary β-rays depends upon the wave-length of exciting γ-rays. It is generally found that β=and γ-rays are emitted together in the same disintegration.

The gamma rays are 100 times more penetrating than beta rays and 10,000 times more than alpha rays. The ionising power of gamma rays, however, is much less 1/100 times that of beta rays and 1/10.000 times that of alpha rays. The gamma rays do not show any deviation in a magnetic or electrostatic field, showing that they do not carry any charge.

Radio-Active Transformation—Radio-Active Series

It has been observed that the phenomena of natural radio-activity is shown by elements of high atomic number. Elements of atomic number 82 and have above nuclear charges exceeding 82 units and are unstable, and break up into simpler atoms ejecting alpha-particles (helium nuclei) or beta-particles (electrons). The radio-active transformations take place in successive stages, forming a radio-active series.

Uranium-Radium Series

The parent element in this series is uranium: atomic weight 238 and atomic number 92, $_{92}U^{238}$. Uranium is comparatively stable but undergoes a slow disintegration at a rate which is uneffected by any means, physical or chemical. In about 5,000 million years, half of the total number of atoms of uranium disintegrate, breaking up into Uranium X_1 and alpha-particles. During an additional 5,000 million years, half of the remaining half would also have disintegrated. This period during which half the atoms of radio-active element disintegrate is called the half-value period or half life and in the case of uranium, it is about 5,000 million years. Uranium X_1 is comparatively less stable (half-value period =24.5 days) and disintegrate into Uranium X_2 and beta particle. Uranium X_2 is still more unstable (half-value period=1.14 minutes) and break up into Uranium II (at. wt. 234), an isotope of parent substance, Uranium I, and a beta-particle.

$$U_1 \xrightarrow{\alpha} U_{x1} \xrightarrow{\beta} U_{x2} \xrightarrow{\beta} U_{II}$$

Uranium II ejects two alpha particles in succession and disintegrates into the most important of the radio-active elements, namely, *Radium*

(at wt. 226, At. No. 88). Radium (Half-value period 1590 years) ejects an α-particle and forms Radon, a chemically inert gas of zero group.

It is more radio-active than Radium. The end-product in the series is Radium G (At. Wt. 206. At. No. 82), an isotope of lead and exhibits no radio-activity.

Rutherford and Soddy's Theory of Radio-active—Disintegration

Rutherford and Soddy in 1902 formulated a theory to explain the spontaneous disintegration of radio-active elements.

Every atom of radio-active element is constantly breaking up into fresh radio-active products with the emission of α, β and γ rays. The new products have entirely new chemical and radio-active properties.

The reaction is spontaneous and can neither be accelerated nor retarded under any circumstance, but is entirely dependent upon the law of chance.

Let us take N atoms of a radio-active element then the rate of disintegration of these atoms will vary as the total number of atoms present.

$$\frac{-dN}{dt} \propto N = \lambda N \quad \ldots(1)$$

where λ is a constant, characteristic of the disintegration and is called the radio-active constant.

$$\frac{dN}{N} = -\lambda dt$$

$$\log N = -\lambda t + A$$

When $t=0$, $N=N_0$ and hence $A = \text{Long } N_0$

$$\text{Long } N = -\lambda t + \log N_0$$

$$\text{or} \quad \text{LOg } \frac{N}{N_0} = -\lambda t$$

$$\text{or} \quad N = N_0 e^{-\lambda t} \quad \ldots(2)$$

The ionisation is proportional to $\frac{dN}{dt}$ and hence a curve between ionisation produced and time will be an exponential curve.

$$\frac{dN}{dt} = -N_0 e^{-\lambda t} . \lambda$$

$$= -\lambda N$$

The equation for growth will be

$$N = N_0 \,(1 - e^{-\lambda t})$$

Radio-active Constant: The radio-active constant can be obtained from equation (2)

$$N=N_0e^{-\lambda t}$$

if time, $$t=\frac{1}{\lambda}$$

we have $$\frac{N}{N_0}=e^{-\frac{1}{\lambda}.\lambda}=e^{-1}=\frac{1}{e}$$

hence the radio-active constant is the reciprocal of the time during which the original number of atoms of a radio-active substance falls to $\frac{1}{e}$ of its value.

Half-Value Period: The half-value period T is defined as the time in which the quantity of radio-active substance is reduced to half of its original value.

$$N=N_0e^{-\lambda t}$$

when $t=\mathrm{T},\ \mathrm{N}=\frac{1}{2}\ \mathrm{N_0}$

$\therefore$ $$\tfrac{1}{2}N_0=N_0e^{-\lambda \mathrm{T}}$$

or $$e\lambda T=2$$

or $$\lambda T=\log e\ 2$$

or Half-value period $$\mathrm{T}=\frac{\log e\ 2}{\lambda}$$

$$=\frac{0.6931}{\lambda}$$

Average Life of the Atom: The atoms of a radio-active substance are continuously in the process of disintegration. Thus some atoms have extremely short lives while others have a long life and hence it is useful to know the average life of the atom.

The average life of an atom is the reciprocal of the radio-active constant, λ

Half-value period $$=\frac{\log e\ 2}{\lambda}=\frac{0.6931}{\lambda}=0.6331\times\frac{1}{\lambda}$$

$$=0.6931\times \text{Average life}$$

Artificial Disintegration or Transmutation

Rutherford observed in 1919, that by the action of α-particles from radio-active radium upon nitrogen nucleus, some particles are ejected which produce scintillations on a *zns* screen. The new particles could not be α-particles or electrons as the former would not have such a long range and latter did not produce scintillations. It was revealed that these long range particles had mass and charge of a proton.

$$_7N^{14}+{_2He^4}\rightarrow{_8O^{17}}+{_1H^1}$$

The nitrogen nucleus was transformed into an oxygen nucleus with the emission of a proton.

This process of producing new stable nuclei out of other stable nuclei is called *artificial transmutation* of elements.

Sherr and Bainbridge in 1941, actually realised the dream of producing artificial gold for the first time from mercury.

$$_{80}Hg^{200} + {}_1H^1 \rightarrow {}_{79}Au^{197} + {}_2He^4$$

Mercury proton gold α-particle

The gold was, however, found to be unstable as so much ill-gotten wealth always is.

Induced Radio-Activity

In 1934, Curie and her husband found that boron, magnesium and aluminium become radio-active after bombardment by α-particles from polonium. This shows that the product of disintegration is radio-active and this undergoes nuclear transformation in the usual way, although the half-value period of such changes is generally small. The phenomena is called artificial or induced radio-activity.

The reaction in the case of aluminium can be respresented thus:

$$_{13}Al^{27} + {}_2He^4 \rightarrow {}_{15}P^{30} + {}_0n^1$$

The product is an isotope of phosphorus and is radio-active, its half-value period being 3 minutes and 15 sec. and is called *radio-phosphorus*. This disintgrates into the stable element silicon and gives out a particle of the same mass and charge as the electron but whose charge is positive. Such a positive electron is called position.

$$_{15}P^{30} \rightarrow {}_{14}Si^{30} + {}_1p^0$$

Radio-phosphorus Silicon Position

Lawrence bombarded sodium with fastly moving deuterons and obtained radio-radium and protons. The radio-sodium was found to be radio-active (half-value period = 15 hrs.) disintegrated into Magnesium and electrons and also emitted gamma rays.

$$_{11}Na^{23} + {}_1H^2 \rightarrow {}_{11}Na^{24} + {}_1H^1$$

Sodium Deuteron Radio-sodium Proton

$$_{11}Na^{24} \rightarrow {}_{12}Mg^{24} \quad {}_1e^0 + \gamma\text{-rays}$$

16

WAVE NATURE OF PARTICLES

The world in which we live is full of light. Light is radiated by the sun, by stars, by glowing electric lamps, by a burning match, and by dazzling flashes of lightning. Light enables us to see the beauty of the universe around. But what is light? What are the nature and structure of it? What processes in matter cause light radiation? These and many other problems have always been of interest to man, but it took centuries before he could riddle them. And small wonder, since an insight into the nature of light gives a clue to the understanding of matter.

According to one of the theories put forward by ancient Greeks, light emanated from the eyes of man and, therefore, he could see objects around him.

The well-known German astronomer J. Kepler who lived in the 17th century considered that light was a kind of substance continually emitted by light-radiating bodies. He was of opinion that the propagation of light was instantaneous.

The first definite viewpoint on the nature of light was formulated by Isaac Newton. He held that light is a flux of specific material particles (corpuscles) which are emitted by luminous bodies and propagate in a homogeneous medium in straight lines with a definite finite velocity.

Newton was the first to observe dispersion of light, with the help of a prism and to give an explanation of this phenomena. He explained colour by the sizes of corpuscles which produced it. "Nothing more is requisite for producing all the variety of colours," Newton wrote, "than that the rays of light be bodies of different sizes, the least of which may make violet and the rest as they are bigger and bigger, may make blue, green, yellow and red." Depending on their sizes, corpuscles travelled with different velocities. Newton held that velocity of light was also dependent on the medium in which it propagated, that it was greater in a denser medium and smaller in a medium or a lower density. He came to this conclusion when trying to explain the laws of refraction and reflection of light. As we shall see later, Newton proved to be right only in the first part of his assertion.

Thus in the end of the 17th century the corpuscular theory of light, otherwise called "Newton's Theory of Emission," came into being. Though generally accepted, the corpuscular theory could not explain many of the phenomena in the behaviour of light such as diffraction, interference and polarization. Such weak points in the corpuscular theory made even Newton's contemporaries feel somewhat dissatisfied with it. In the same 17th century, only some year after Newton's theory of emission, Huygens, a Dutch physicist, denied the existence of light corpuscles. According to his theory light had a vibrational character and is a kind of elastic impulse propagating in a specific medium, the ether which pervaded all spaces. Huygen's theory postulated the presence of the aether in water, air, glass, and even in vacuum. In Huygen's opinion, the propagation of light in the aether was analogous to the propagation of sound in air, both the phenomena being of resembling waves of undulatory character.

In the late 18th and early 19th centuries some scientists could quite successfully account for a number of phenomena with the help of the wave theory of light. Thus, after the British scientist Thomas Young had thoroughly investigated the interference and diffraction of light, the French scientist Fresnel gave full theoretical interpretation of these phenomena, reasoning from the wave theory. Fresnel offered a consistent explanation of all the experimental data on the diffraction and interference known by that time. He also put forward the idea that light vibrations were transverse, which permitted the polarisation phenomena to be understood and explained.

In 1849, the French physicist Armand Fizeau measured the velocity of light in air 300,000 km/sec. One year later another French physicist Leon Foucalt determined the velocity of light in water.

It was found that the velocity of light in water was approximately 1.33 times less than in air. For the first time the validity of Newton's and Huygen's hypotheses on the refraction of light at the boundary between two media could be practically tested. Foucalt's experiment on the velocity of light in water was crucial between the two theories: it did not confirm Newton's hypothesis and decided in favour of the wave theory.

Thus in the end of the 19th century, the wave theory of light at last won recognition.

Wave theory of light fails to explain the phenomena like photo-electric-effect and compton-effect. By the end of 19th century it was established that light travels in the form of waves. But in 1901, Planck proposed that light consists of energy packets called quanta, in order to explain black body radiation. In 1905, Einstein applied quantum theory to explain photo-electric effect and compton effect. With this the scientists were left with no other alternative but to accept the dual nature of radiant energy.

But the nature of light was still an enigma. As before, the corpuscular theory and wave theory had their adherents. Quite a number

of phenomena could well be explained from the stand-point of the wave theory, while the corpuscular theory could offer no explanation for them; other phenomena, on the contrary, could well be described with the help of the corpuscular theory but could not be described at all in terms of the wave theory.

Matter is made of particles, corpuscular in nature. But in 1924, Louis de Broglie, the French physicist put forward the bold suggestion that matter which is ordinarily considered as made up of discrete particles—molecules, atoms, protons, electrons and the like—might exhibit wave like nature under appropriate conditions. This means that matter like variation has a dual nature. The waves associated with material particles like electrons, protons are called Matter Waves. This suggestion was based on the following reasoning.

1. *Nature Loves Symmetry:* Nature manifests itself in two fundamental forms, matter and energy. These two forms must be symmetrical. Radiant energy has been proved to possess dual nature, wave and particle; matter also posses the same dual nature, particle and wave.

2. *Mass-Energy Equivalence*: According to Einstein's mass-energy relation, mass can be converted into energy and *vice-versa.* Since radiant energy behaves as wave and particle both, hence the matter characterised by mass should also behave as particle and wave both.

3. *The close parallelism between Mechanics and Optics:* In optics, we are aware of Fermat's principle of least time. According to this principle, a ray of light chooses always the path for which the time of transit is minimum as represented by the relation $\delta \int_{P_1}^{P_2} \mu \, ds = 0$. In mechanics, Maupertian principle of least action suggests that material body follows the path along which work done is minimum. It can be represented by the relation $\delta \int_{P_1}^{P_2} (m\mu) \, ds = 0$. Clearly the facts relating the machanics and optics are explained on the same lines, hence matter should behave like light.

4. *Bohr's Theory of Atomic Structure*: Spectral emission was explained by Niel Bohr on the basis of quantum theory of light. According to this theory, the electrons move in those stationary orbits for which the total angular momentum of moving electron is an integral multiple of $h/2\pi$. While studying the motion of stretched strings and interference of sound waves, we also talk of an integer n. Hence we conclude that like light, matter should also possess wave-like nature.

These reflections led Louis de Broglie to make bold suggestion in

his doctorate thesis on the new idea that there is an intimate connection between waves and corpuscles not only in case of radiation, but also in case of matter. He was awarded Nobel Prize for his suggestion of matter waves in 1929.

Let a particle of mass m travelling with a velocity u, according to De Broglie, it will be associated with a wave, whose wavelength is given by $\lambda=\frac{h}{mu}$ where h is Planck's constant. These matter waves should show the interference and diffraction effects as shown by light or X-rays.

The hypothesis of De Broglie was first experimentally verified by Davison and Germer in 1927. They sent a beam of electrons from an "electron gun" and allowed it to fall on the surface of Nickel Crystal, the reflected beam was received in a Faraday chamber connected to a quadrant electrometer. The diffraction phenomena was observed as with light rays. They observed that for different accelerating potentials, the beam was diffracted in different directions. Calculating the wavelength like that of X-rays from the equation d Sin $\theta=n\lambda$, in one of the experiments they found that 54 ev beam gave an angle of diffraction of 50° for a nickel crystal. Taking $d=2.15$ A.U. and $n=1$ $\lambda=2.15$ Sin $50°=1.65$ A.U. The theoretical formula gives.

$$\lambda=\frac{12.27}{\sqrt{54}}\text{ A.U.} = 1.669\text{ A.U}$$

The close agreement between the two values confirms the validity of De Broglie's theory. Hence matter, like light, also possess dual nature. When a material particle behaves as a corpuscle, it reveals its one half, and when it behaves wave, it reveals other half, but in no case does it reveal it fully. Matter and Energy are the two phases of the same thing.

Applications

1. Bohr's stationary orbits.
2. Electron microscope.

17

THEORY OF TRANSISTORS

The transistor—an entirely new type of electron device has come into its own and bids to replace the bulky electron tubes in most, if not all applications. Transistors are far smaller than tubes, have no filament and hence need no heating power, and may be operated in any position. They are mechanically rugged, have practically unlimited life; and being a solid is not enclosed in vacuum. In contrast to electron tubes, which utilise the flow of free electrons through a vacuum or gas, the transistor relies for its operation on the movement of charge carriers through a solid substance, a *semi-conductor*.

The operation of thermionic tube depends upon the flow of electrons from the filament to the plate and control of this flow by intermediate grids. The operation of the transistor is dependent upon the flow of electrons and what one called holes, and their regulation. However, the thermionic value is a voltage-regulated device, whereas the transistor is a current regulated device.

The materials one classified as semi-conductors, if their electrical conductivity is intermediate between metallic conductors, which have a large number of free electrons available as charge carriers, and non-metallic insulators, which have practically no free electrons available to conduct current. There are many varieties of semi-conductors, but the two most frequently used in electronics and transistor manufacture, are germanium and silicon. Both elements have some crystal structure and similar characteristics, so that the discussion that follows for germanium will also apply to silicon.

Germanium Crystal Structure

The outer-most electron shell of an atom is of interest in electronics, since it contains the loosely held valence electrons, which are easily dislodged to become electric current carriers. Germanium has four valence electrons in its outer shell, and for our purpose, the atom may be pictured as containing only these electrons and four protons in the nucleus to keep it electrically neutral when germanium is in crystalline form its atoms assume the typical diamond structure illustrated in Fig. 12.1. In this structure adjacent germanium atom share their valence electrons in a strong bond, so that effectively four

orbital electron pairs are associated with each nucleus. These electron pairs are termed covalent bonds and they are bound so strongly to each other and to the nucleus that no free electrons are available to con-

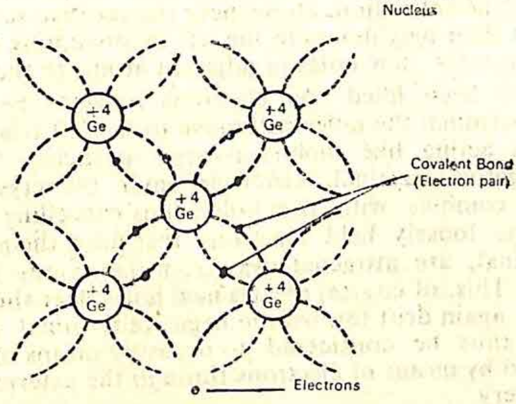


Fig. 12.1 Germanium Crystal Structure Showing Co-valent Bonds.

duct a current through the germanium. A pure germanium crystal, therefore, is practically a non-conductor of electricity. It is not completely non-conducting, since ordinary heat energy occasionally disrupts some of the covalent bonds, thus liberating free electrons as charge carriers.

If a small amount of an impurity is introduced into the germanium crystal, its current-conducting characteristics change radically. Thus, when atoms that have five electrons in their outer shell, such as antimony or arsenic, are introduced into the germanium atom (a procedure known as doping), the fifth electron of the impurity atom does not find a place in the symmetrical covalent bond structure and, hence, is free to roam around through the crystal. These free electrons are then available as electric current carriers. By placing an electric field across the "doped" germanium crystal, the excess-free electrons donated by the impurity atoms will travel toward the positive terminal of the voltage source. Relatively few impurity or "donor" atoms within the germanium structure permit fairly substantial electron currents through the crystal when an electric field is applied. Germanium that has been doped by pentavalent donor atoms (i.e., five electrons in the outer shell) is known as *N*-type germanium, because current conduction is carried on with negative charge carriers, or electrons.

Consider now the situation when an impurity that has only three electrons in its outer shell, such as gallium or indium, is introduced into the pure germanium structure, but one of the covalent bonds around each indium atom has an electron missing, or a *hole* in its place. Although the hole indicates the absence of an electron, it behaves like a real, positively charged particle when an electric field

is applied across the crystal. Under the influence of the electric field, electrons within the crystal will tend to move towards the positive terminal of the voltage source and jump into the available holes of the indium atom near the positive terminal. Since there are no free electrons available, the deficient indium atoms near the positive terminal 'steal' electrons from their neighbours to the left by disrupting their covalent bonds. This creates new holes in adjacent atoms to the left of those that may have been filled. As electrons move to the right toward the positive terminal the holes will move to the left towards negative terminal, thus acting like mobile positive particles. As the holes reach the negative terminal, electrons enter the crystal near the terminal and combine with the holes, thus cancelling them. At the same time, the loosely held electrons that filled the holes near the positive terminal, are attracted away from their atoms into the positive terminal. This, of course, creates new holes near the positive terminal, which again drift toward the negative terminal. Current conduction may thus be considered to occur by means of holes inside the crystal, and by means of electrons through the external connecting wires and battery.

An impurity that has three electrons in its outer shell (trivalent) is known as an acceptor atom, because it takes electrons away from surrounding germanium atoms. Germanium that has been doped with trivalent acceptor atoms is called *P*-type germanium, to specify that current conduction is carried on by holes, which are the equivalent of positive charges.

P-N Junction Diodes

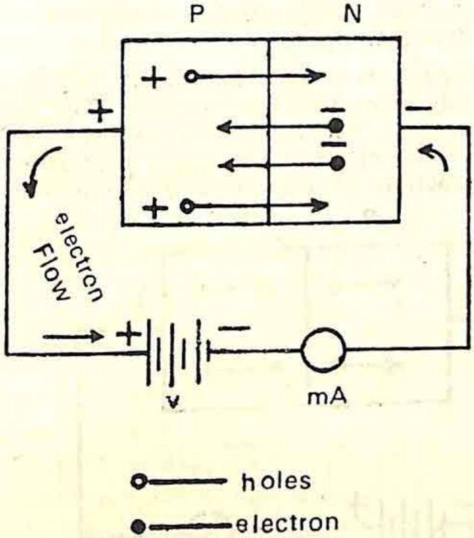
Conduction of electric current through *P*-or *N*-type germanium takes place equally well in either direction; hence, reversing the polarity of the battery will not effect the amount of current flow, although it reverses its direction.

Consider now what happens when *P*-type germanium is joined to *N*-type germanium and a voltage is applied across the junction, as illustrated in Fig. 12.2. In practice, such an abrupt *P-N* junction may be obtained in two ways. In the grown junction on single crystal is obtained from a melt which at first contains impurities of either the *P*-or *N*-type. In the middle of the growth process, impurities of the opposite kind are added to the melt, so that the remainder of the crystal grows into the opposite type.

In contrast, a fused *P-N* junction is obtained by pressing small "dots" of indium (*P*-type) on a wafer of *N*-type germanium. After a few minutes of heat treatment, the indium fuses to the surface of the germanium and produces *P*-type germanium for a thin layer below the surface. A *P-N* junction is thus formed between this *P*-region and the remainder of the *N*-type germanium wafer.

With the *P*-type germanium biased positively, the (positive) holes are repelled by the battery voltage toward the junction between the

P-and *N*-type material. Simultaneously, the electrons in the *N*-type germanium are repelled by the negative battery voltage toward the



Current Flow Across P-N Junction with Forward Bias

Fig. 12.2

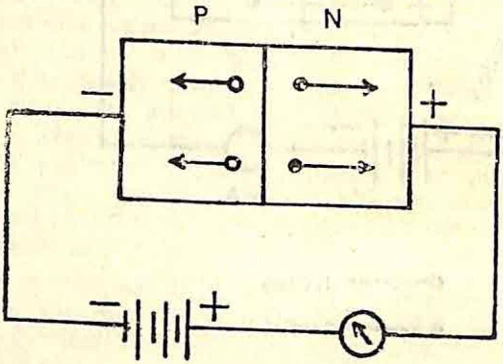
P-N junction. Although there is normally a potential barrier at the *P-N* junction that prevents electrons and holes from moving across and combining under the influence of the electric field of the battery, the holes move to the right across junction and the electrons move to the left. In the region of the *P-N* junction, therefore, electrons and holes meet and combine, thus ceasing to exist as mobile charge carriers. For each electron hole combination that takes place near the junction, a covalent bond near the positive battery terminal breaks down, an electron is liberated and enters the positive terminal. This action creates a new hole which is to the right toward the *P-N* junction.

At the opposite end, in the *N*-region near the negative terminal, more electrons arrive from the negative battery terminal and enter the *N*-region to replace the electrons lost by combination with holes near the junction. These electrons move toward the junction at the left, where they again combine with new holes arriving there. As a consequence, a relatively large current flows through the junction.

The battery connection that permits current to flow across the *P-N* junction is known as forward bias. A minimum voltage of about 0.1

volt is needed to overcome the potential barrier at the junction and permit any current to flow. The current then increases rapidly with increasing battery voltage and as little as one to two voltage permit currents of 20 to 100 milliamperes.

If the battery voltage is reversed in polarity, as illustrated in Fig. 12.3, an entirely different situation prevails. The holes are now attracted to the negative battery terminal and move away from the *P-N* junction while the electrons also move away from the junction because of the attraction of the positive terminal. Since there are



P-N Junction With Reverse Bias

Fig. 12.3

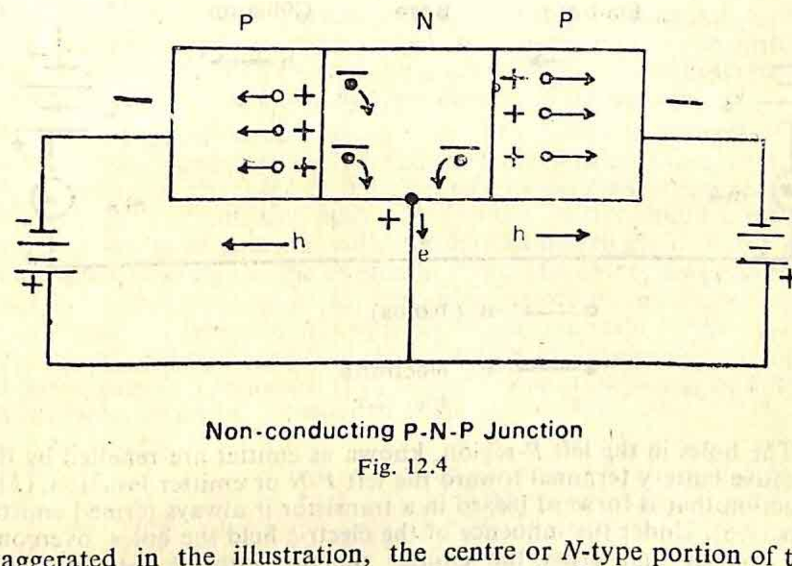
effectively no hole and electron carriers in the vicinity of the junction, current flow stops almost completely. A small reverse current of a few microamperes still flows across the junction. This reverse current is due to the thermally generated electron-hole pairs within both the *P*- and *N*-type materials. As mentioned before, some covalent bonds always break down because of the normal heat energy of the crystal molecules. Electrons liberated by this process in the *P*-material move right across the junction under the influence of the electric field, while holes generated in the *N*-material move to the left into the *P*-material. Thus a small electron-hole combination current is maintained by these so-called minority carriers If the reverse bias is made very high, the covalent bonds near the junction break down, and a large number of electron-hole pairs will be liberated; the reverse current then increases abruptly to a relatively large value.

The unilateral current conduction characteristic of a *P-N* junction is seen to be similar to that of the conventional diode tube. It was pointed out that this characteristic permits diode tubes to change alternating current into unidirectional current. Germanium and other semiconductor diodes (Silicon, Selenium, etc.) are, therefore, extensively used as rectifiers and detectors.

Junction Triode Transistors

Just as the triode tube followed on the heels of the vacuum diode, you might expect that the logical extension of the semi-conductor diode junction would be a triode junction, consisting of two *P-N* junctions. This is indeed the case, and the modern *P-N-P* or *N-P-N* junction triode transistors are in many respects analogous to triode electron tubes. A junction transistor can function as an amplifier or oscillator as can a triode tube, but has the additional advantages of long life, small size, ruggedness and absence of cathode heating power.

Fig. 12.4 illustrates a *P-N-P* junction, made up of a sandwich of two *P-N* germanium junction diodes, placed back to back. Although



Non-conducting P-N-P Junction
Fig. 12.4

exaggerated in the illustration, the centre or *N*-type portion of the sandwich is extremely thin in comparison to the *P*-region. The double junction may be either of the grown or fused crystal types, obtained in the manner discussed for junction diodes.

With the battery polarities as shown in Fig. 12.4, the *P*-regions are negative with respect to the central *N*-region or conversely, the *N*-region (called the base) is positive with respect to the *P*-regions. The mobile electrons in the *N*-region, therefore, initially move away from both junctions in the direction of the positive connecting terminal. The holes in each of the *P*-regions also move away from the junctions and are attracted towards the negative terminals. After these initial displacements of holes and electrons the current flow stops.

Consider now the same *P-N-P* sandwich, but with the batteries connected as in Fig. 12.5. Note that the *P*-region at the left is biased positively, in the forward direction, while the *P*-region at the right is

biased negatively, in the reverse direction. This is one of the basic operating connections of a *P-N-P* junction transistor.

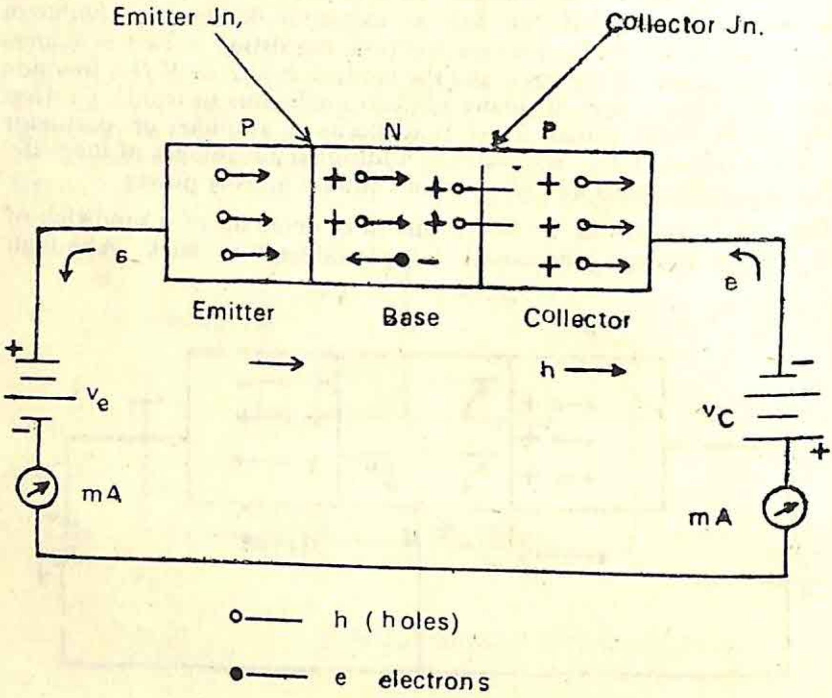


Fig. 12.5

The holes in the left *P*-region, known as emitter are repelled by the positive battery terminal toward the left *P-N* or emitter junction. (The junction that is forward biased in a transistor is always termed emitter junction). Under the influence of the electric field the holes overcome the barrier and cross the emitter junction into the *N*-type or base region. This region is very thin and only lightly "doped" with impurity atoms, so that the majority of the holes are able to drift across the base without meeting electrons to combine with. A small number of holes (about five per cent), however, are lost in this area because of recombination with electrons. The remainder penetrate through the almost porous base region and flow across the right junction into the *P*-region or collector. (The junction with a reverse bias in a transistor is termed collector junction). The negative collector voltage (V_c) aids in rapidly sweeping up the holes that pass into the collector region.

As each hole reaches the collector electrode an electron is emitted from the negative battery terminal (V_c) and neutralises the hole. For each hole that is lost by combination with an electron in the collector and base areas, a covalent bond near the emitter electrode breaks

down and a liberated electron leaves the emitter electrode and enters the positive battery (V_e). The new hole that is formed then moves immediately towards the emitter junction, and the process is repeated. It is evident, therefore, that a continuous supply of holes are injected into the emitter junction, which flow across the base region and collector region, where they are gathered up by the negative collector electrode current conduction within the *P-N-P* transistor thus takes place by hole conduction from emitter to collector, while conduction in the external circuit is carried on by electrons. Furthermore, the collector current must be less than the emitter current by an amount proportional to the number of electron hole combinations occurring in the base area.

The ratio of collector current to emitter current is known as alpha and is a measure of the possible current amplification in a transistor. From the definition, alpha cannot be greater than one, but practically values of 0.95 to 0.99 are attained in commercial transistors.

Because of the reverse bias no current can flow in the collector circuit, unless current is introduced into the emitter. Since a small emitter voltage of about 0.1 to 0.5 volt permits the flow of an appreciable emitter current, the input power to the emitter circuit is quite small. As we have seen, the collector current due to the diffusion of holes is almost as large as the emitter current. Moreover, the collector voltage (V_c) can be as high as 45 volts, thus permitting relatively large output powers A large amount of power in the collector circuit may thus be controlled by a small amount of power in the emitter circuit. The power gain in a transistor (power out/power in) thus may be quite high reaching values in the order of 1000.

18

ATOMIC STRUCTURE

The first model of the atom, fundamental for our present day concepts of its structrure, is due to the great British physicist Ernest Rutherford. He suggested that the atom consists of a positively charged nucleus in which almost the whole mass of the atom is concentrated and of negatively charged electrons revolving about the nucleus in certain orbits.

The model was advanced by Rutherford as a result of his numerous experiments on the bombardment of targets made of different elements with thin bunches of helium nuclei, carried out in 1911.

At first sight Rutherford's model of the atom has much in common with the model of the solar system. For this very reason Rutherford's model of the atom was called planetary.

Rutherford's model, however, was not free from certain disadvantages. For instance, it could furnish no explanation of the exceptional stability of the atom.

Reasoning from the laws of classical physics the revolution of electrons about the nucleus cannot be stable, since as any accelerated motion of charged particles, it must be accompanied by electromagnetic radiation. An electron moving in a circular orbit even with a constant speed, possesses an acceleration according to the laws of classical physics. For an electromagnetic field to be set up a certain amount of energy is to be expanded Therefore the energy of the electron must gradually diminish and the speed of its motion gradually decrease. Eventually the electron should spiral down into the nucleus. It can be calculated that with an atom of hydrogen this process would be completed in about 10^{-8} seconds. Experimental, practical evidence, however, does not confirm such behaviour of electrons. On the contrary, atoms are very stable and can exist for as long as many a thousand million years.

In 1913, the Danish physicist Niels Bohr was successful to find the correct way out of this difficulty and explain the origin of line spectra of different elements as well as the stability of the atom. Bohr showed that the laws of classical physics could not be applied to intra-atomic processes and that such processes should be interpreted in terms of quantum theory.

He (Niels Bohr) maintained that the electron in the atom is restricted to particular stable orbits (or shells) which are at different distances from the nucleus; the electron can never be found between such orbits. As long as the electron remains in steady definite energy states, it does not radiate or absorb electromagnetic waves. The electron can pass from its one steady state to another only in a jump. Such transitions are accompanied by radiation or absorption of electromagnetic waves.

With the atom passing from one steady state of energy E_2 to another one E_1, the radiation or absorption of e.m. waves is always in integral quanta only, and the frequency of radiation (absorption) ν, multiple of Plank's constant h, is given by the formula

$$E_2 - E_1 = h\nu$$

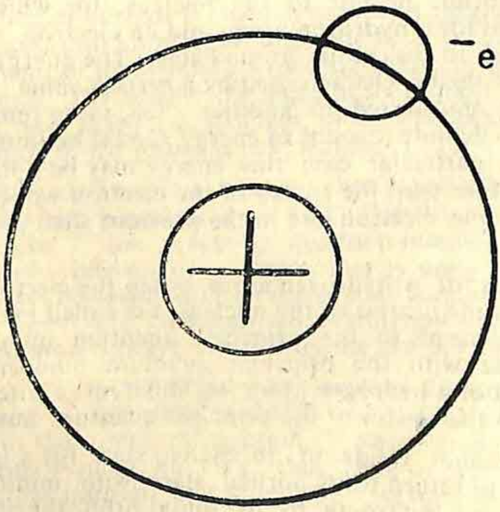
As this can be seen from this formula, the frequency of radiation depends only on the difference between the energies the atom had in its respective energy states, whereas, according to classical physics, the frequency of radiation is in no way related to the amount of the energy radiated.

The Bohr theory could well describe the discrete spectrum of the one electron atom of hydrogen, but could not account for the spectrum of an atom as simple as helium having two electrons. Nor could Bohr's theory explain the relationship between the intensities of different lines in the atomic spectrum.

Structure of the Atom

Quantum Numbers

Let us consider the structure of the atom taking as an example



Proton $=1$
Neutron$=0$
Electron$=1$

Model of H_2 atom

Fig. 13.1

the simplest case of a hydrogen atom. A hydrogen atom consists of a nucleus (proton) and an electron moving about the nucleus in definite orbits (shells). The electron and the proton are charged particles and their energies are equal in magnitude but opposite in sign. As a whole, the hydrogen atom is electrically neutral. The nucleus of hydrogen and its electron are mutually attracted by the electrostatic force and, therefore, the electron does not fly away from the nucleus.

To make the characteristic of the hydrogen atom more complete, it should be mentioned that the mass of its nucleus is 1836 times that of the electron. The mass of hydrogen atom is thus practically determined by the mass of its nucleus (proton). The mass of the atom is 1.67×10^{-24}g. The diameter of a hydrogen atom is approximately equal to 10^{-8} cm. This value corresponds to one angstrom. The dimensions of an atom cannot be determined precisely; its boundaries are somewhat fuzzy.

The radius of the nucleus of a hydrogen atom is about one hundred thousandth that of the atom and equals 1.3×10^{-13} cm. The density of the substance in the nucleus is extremely high, it comes to about 2.10^{14}g/cm^3, that is to about two hundred million tons per cubic centimeter.

The orbits or shells an electron can occupy in an atom are designated by letters *K*, *L*, *M*, *N* etc. Therefore, an electron occupying the shell nearest to the nucleus is called *K*-electron. The shells can be numbered by ascribing respective numeric symbols 1, 2, 3, 4, etc., to them. These numbers are called principal quantum numbers and denoted by the symbol n.

The lowest orbit, nearest to the nucleus, for which $n=1$ is the most stable orbit for a hydrogen atom, and an electron in this orbit or shell is said to be in its ground state. The energy the electron possesses in this shell is characterised by a certain value E_1. For the electron to be transferred to another shell, more remote from the nucleus, a quite definite amount of energy should be imparted to the electron. In a particular case this energy may be a light quantum, photon. In another shell the energy of the electron will be E_2, equal to the energy the electron had in the previous shell plus that of the photon.

All the states of a hydrogen atom, when the electron occupies a shell other than the nearest to the nucleus, are called excited states. If we relate this concept to the principal quantum numbers, excited states are those with the principal qnantum number greater than unity. The radii of a hydrogen atom in different excited states are proportional to the square of the principal quantum number.

The atom cannot reside in an excited state for a long period of time and tends to return to its normal state with minimum energy. With the electron returning to its initial orbit, the atom emits the same amount of energy it had received, as a quantum of e.m. radiation

$h\nu$. Similar transitions in the atom can take place between other orbits as well. As a result, there is a whole series of frequencies constituting the emission spectrum of an atom. Energy atom has its own strictly definite spectrum of frequencies. The more complicated the structure of the atom, the more complicated its spectrum is.

Not only the energy of an electron, but other characteristics of the atom are also quantised.

The electron possess an angular momentum. As is known from mechanics, angular momentum of a particle is the product of its mass, velocity and the distance of the mass from the centre about which it rotates. According to quantum mechanics, the angular momentum of an electron is quantised as well, i.e., it can have not any arbitrary, but quite definite values, known as orbital quantum numbers. These numbers are denoted by the letter L. The maximum value of the orbital quantum number for a given shell is equal to the principal quantum number minus unity. For example, for the shell M, $n=3$. The possible values of the orbital quantum numbers for this shell are $L=2$, $L=1$, $L=0$. The states corresponding to the values of $L=0$, 1,2,3, etc., are denoted by respective letters s,p,d,f, etc.

The principal quantum numbers characterise the value of the energy of the electron, which depends on the radial distance of the electron from the nucleus. Orbital quantum numbers express possible values of the angular momentum of the electron in the orbit.

Besides these, there are two more quantum numbers so that the total number of possible states of an eletron in the atom is still greater. It is known that an electron, while in orbit, creates electric current and, as a result, a magnetic field is set up. The magnitude of the magnetic field due to circular current is characterised by a magnetic moment. If an atom is placed into an external magnetic field, the direction of the magnetic moment of the orbital current may happen to be at a certain angle to this field. The smaller the angle of inclination, the greater the projection of the magnetic moment of the orbital current onto the direction (vector) of the external field will be.

The projection of the orbital moment onto the vector of the external magnetic field is also a quantised variable. For the orbital quantum number equal to l, the magnetic quantum number can take up all values from l to l—differing from one another by unity. In the magnetic field the sub-level corresponding to the orbital number l consists of $2l+1$ states which are characterised by different magnetic quantum numbers. These numbers are denoted by the symbol ml.

The electron has its own angular momentum termed as the spin. The spin is also a quantised variable. It can be either parallel or anti-parallel to the orbital momentum. The spin quantum number is denoted by the symbol m_z. We, thus, have to deal with a series of different quantum states of the atom. The picture of energy levels for atoms with a large number of electrons is extremely complicated.

19

CARBON—THE BASIS OF LIFE

Carbon and its Oxides

Most, if not all, combustible substance used as fuel consist of carbon or carbonaceous materials, and since animal heat is the outcome of the slow combustion of food-stuffs, these also may be included under the term fuel. Carbon itself is an element, that is, a substance which has hitherto not been decomposed, and it does not occur free in nature except in two mineral forms: graphite, also known as plumbago or black-lead, and diamond. Soot may be looked upon as impure carbon, while lampblack, the purer soot obtained by burning heavy oils, is well known as a pigment. To these must be added the different kinds of charcoal, obtained by heating in a confined space any carbonaceous substance whatsoever, such as bones, wood, or coal. Bone charcoal or animal charcoal has a most remarkable power of absorbing gases and removing colouring matters, and on this latter score it is regularly used in sugar-refineries in order to clarify sugar. A piece of wood charcoal will absorb more than eighty times its own bulk of ammonia gas, and a similar action occurs with drain gases, the latter being not only absorbed but also rendered harmless. Another form of charcoal which is extensively used where great power of absorption required are made from the shells of coconuts; it is used in respirators and gasmasks, or wherever gases must be removed by absorption. Gas coke, the charcoal obtained from common coal in gas-works, is now very largely employed in filtering sewage, and compressed carbon blocks are also used in domestic filters for drinking water. Foundry coke is made from coal by heating in suitable ovens to which only a limited supply of air is admitted. During the coking process many by-products are given off; such as tar, ammoniacal vapours, and gases of various kinds. In short, the whole process resembles very closely that of making coal-gas. Ivory-black or bone-black is a pigment formed by grinding down bone charcoal. Graphite or black-lead fills an important niche in the industrial world, being extensively used for lead pencils, for polishing grates, for crucibles, either alone or mixed with fire clay, in connection with smelting metals, for electric lamps of the arc pattern, and lastly, to the form of powder, as a lubricant where oils are unsuitable. The properties and uses of diamonds are too well known to require

mention. Many diamonds, by reason of defects of colour or structure, are unsuited for jewellery but they are of the utmost value in cutting and polishing precious stones and even, in the form of a diamond drill, for rock-boring and other mining operations.

In industry, diamonds are used for glass-cutting and for machining hard and tough metals. A soft iron disc, its edge charged with diamond dust, acts as a glass saw. Tools for turning and boring tough metals, at high speed, may be provided with cutting tips made from diamonds. The dies through which fine wires are drawn are made from diamonds, so that the hole will not enlarge as a result of wear.

Carbon, thus, presents the curious phenomenon of an element capable of appearing under widely different physical forms. All these varieties are identical in chemical composition and behaviour, yet they vary in appearance, specific gravity, power of conducting heat and electricity, power of combining with oxygen and so on. This phenomenon is known as allotropy and carbon shares the possession of allotropic forms with oxygen, sulphur, phosphorus, silicon and many other elements.

Since diamond and graphite are simply allotropic forms of carbon, many attempts have been made to form them artificially. In making cast-iron and steel, graphite scales are often formed as the result of the separation of carbon originally present in the form of coke. Under the great heat and pressure of a blast-furnace the melted metal actually dissolves a certain portion of carbon, but often re-deposits some of this in cooling, in the form of graphite scales. Again in the retorts used in making coal-gas there is often found an internal coating of artificial graphite known as gas carbon, arising from the decomposition of hydrocarbon gases within the retort. Given conditions of slow-cooling under sufficient pressure, it should not be impossible to produce artificial diamonds from, say, lampblack or other form of charcoal. These conditions, however, were difficult to find, and though the discovery of artificial diamonds dates from 1880, and despite the expenditure of considerable sums of money by ingenious investigators, artificial diamonds have never been produced in either commercial quantities or quality good enough for use as gems.

When carbon or anything containing carbon is burned in plenty of air, carbon dioxide, popularly called carbonic-acid gas, is formed, and this gas is readily recognised by the facts that it extinguishes a light and turns lime-water milky, forming carbonate of lime. This is the gas always found in mines after an explosion, and it is called by the miners after-damp, black-damp, or choke-damp, because it not only refuses to support combustion, but is unable to sustain life. Air containing more than one per cent of carbonic acid is distinctly unfit for breathing though it will easily support combustion, and since this gas is given off as a waste product in the breath, ways must be taken either to remove it or to dilute it largely with fresh air.

Another method of forming carbonic acid gas is by expelling it from its compounds, called carbonates by means of almost any acid. The carbonate generally used in domestic circles is baking soda, which is bicarbonate of soda, and the acid is usually tartaric acid in crystals. In home baking, however, other acid substances are used, such as butter-milk, which contains lactic acid, by cream of tartar, which is acid tartrate or bitartrate of potash, and so on. It is important to observe that, whereas yeast leaves no residue in baking, these chemical substances form new combinations which remain in the bread. Thus tartaric acid and baking soda give carbonic acid gas, but they also form tartrate of soda, which remains behind. If cream of tartar be used instead of tartaric acid, the residual product is the double tartrate of soda and potash familiar under the name of Rochelle salt. On the manufacturing scale for use in aerating water this gas is sometimes obtained by the action of dilute hydrochloric acid upon marble. This substance is one of the many forms of carbonate of lime and, as in the carbonaceous rocks, an interesting series may be obtained, starting from the shells of the living animal through shell limestone, coral limestone, and chalk, upto limestones in which all traces of shell structure have disappeared and so to marble, a metamorphic or altered limestone, and finally calcite and Iceland spar, the purely crystalline form. Of recent years aerated waters have been carbonated by the use of compressed carbonic acid gas recovered from breweries or lime-kilns and stored under pressure in steel cylinders. By increased pressure that gas may be liquified and even frozen, solid carbonic acid resembling flakes of snow. Solid carbon dioxide is much used as a refrigerant in preference to ice because it is dry, leaves no mess, gives a lower temperature and is more economical. When compressed, it forms a hard, ice like mass, and is marketed under the trade name of "Drikold." One popular and familiar application is to be seen all over the country wherever ice-cream bricks are sold. These may be kept for some considerable time in perfect condition, thanks to the reduced temperature which solid carbon dioxide creates. The name "soda water," as usually applied, is a misnomer; such water rarely contains anything except an over-charge of carbonic acid gas. True soda water contains dissolved bicarbonate of soda. Although added as carbonate, the carbon dioxide changes it to bicarbonate. Most effervescing drinks, such as beer, champagne, lemonade, owe their sparkling character to this gas, produced by fermentation, as in beer and wine, or chemically as in most aerated waters and health-salts.

The Distillation of Coal

Apart from ammonia, NH_3, the most useful by-product of coal-distillation is tar. Tar is a highly complex mixture of substances belonging to different chemical families. It contains hydrocarbons, of which benzene may be taken as the type; carbolic acid and similar compounds containing carbon, hydrogen, and oxygen; sulphur

compounds; nitrogen compounds like ammonia and aniline, the base of the well-known dyes; and lastly, those highly carbonaceous substances which go to form pitch.

The carbolic and creosote oils which form the next fraction in tar distillation are often taken together under the name of heavy oils, and they contain creosote, carbolic acid, and naphthalene. Commercial carbolic acid contains cresol as well as phenol, the latter being pure carbolic acid, used for medicinal purposes. Its appearance and use as disinfectant are well-known, though in this latter respect it is rather an antiseptic, arresting growth, than a positive germicide.

Naphthalene is another solid obtained from creosote oil. In the form of cakes (moth balls) it is used as an insecticide instead of camphor, and also for enriching coal gas.

Anthracene oil, or green oil, is also the liquid product of coaltar, and is chiefly valuable on account of containing anthracene, another basis of dyestuffs, especially of alizarin, or artificial madder, used for Turkey red.

Carbon and its Compounds

(*i*) *Urea*: NH_2 CO. NH_2, a very useful fertiliser.

(*ii*) *Paraffins*: The compounds of carbon and hydrogen called hydrocarbons. The paraffins do not react at all easily with other substances, it is to this lack of chemical affinity that their name is due.

(*iii*) *Methyl alcohol*: It can be produced synthetically by passing a compressed mixture of water-gas and hydrogen over a heated catalyst consisting of zinc oxide and chromium oxide.

$$\underset{\text{Coke Steam}}{C+H_2O} \rightarrow \underset{\text{Water gas}}{CO+H_2}$$

Catalyst

$$\underset{\text{Water gas and hydrogen}}{CO+2H_2} \longrightarrow \underset{\text{Methyl alcohol}}{CH_3OH}$$

It is used as a solvent in the preparation of lacquers and varnishes, in the organic industry it is used directly or indirectly in the manufacture of many fine chemicals, such as drugs, dyes and photographic chemicals.

(*iv*) *Ethyl alcohol* also called spirit or wine is obtained by both synthetic methods and fermentation processes. The simplest method is the fermentation of sugars, such as glucose, by means of yeast, as in the brewing of beer, making wine and spirits.

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \xrightarrow{\text{Zymase*}} \underset{\text{Ethyl alcohol}}{2C_2H_5OH} + 2CO_2$$

**Zymase*: These are catalysts called enzyme which convert glucose into alcohol.

Glucose, suitable for this fermentation reaction, can be readily produced, in quantity, by treating starch with hot dilute acid.

(*v*) Ether is well-known as an anaesthetic. If methylated spirit is used instead of alcohol, we get methylated ether, which is less pure, being mixed with dimethyl ether.

(*vi*) *Aldehydes and Acetones*: If alcohol is oxidised, by means of chromic acid, we obtain aldehyde, the name is derived from dehydrogenated alcohol. Methyl alcohol yields the gas from aldehyde, H.CHO, when dissolved in water, is known as formalin. The oxidation of ethyl alcohol gives acetaldehyde, CH_3. CHO.

Aldehydes are very reactive, and have many uses in synthetic organic chemistry. They are active reducing agents and will reduce ammoniacal silver nitrate to produce silver mirror. This provides a means of silvering glass by chemical means. An important acetone finds many uses as a solvent, particularly in the preparation of varnishes, cordite (smokeless powder) and celluloid.

A most important substance, aniline, is obtained from coaltar; it is an amine with the formula $C_6H_5.NH_2$, and is the starting point for numerous dyestuffs, often called aniline dyes.

A much-improved pain-reliever. 'Aspirin,' is derived from salicylic acid which is again a compound of carbon.

20

AQUEOUS ACIDS AND BASES

The acids . . . are compounds of two substances . . . the one constitutes acidity, and is common to all acids . . . the other is peculiar to each acid, and distinguishes it from the rest . . .

A. Lavoisier, 1789

Consider the following compounds:

HCl	: Hydrochloric acid (or Hydrogen Chloride)
HNO_3	: Nitric Acid
$CH_3\ COOH$	: Acetic acid
H_2SO_4	: Sulfuric acid
H_3PO_4	: Phosphoric acid

Each of these five compounds shares the following important properties.

1. *Hydrogen containing*: Each of these compounds contains hydrogen.
2. *Electrical conductivity*: Each of these compounds dissolves in water to form solutions that conduct electricity. Ions are present in these solutions.
3. *Liberation of hydrogen gas*: The aqueous solutions of each compound produce hydrogen gas, H_2, if zinc metal is added.
4. *Colour of litmus*: Litmus, a dye, is red in colour when placed in these aqueous solutions.
5. *Taste*: The dilute, aqueous solutions, of each compound are sour tasting.

What is the common factor that makes these different substances behave in the same ways? In water they all form conducting solutions; we conclude that they all form ions in water. Each substance contains hydrogen and each reacts with zinc metal to produce hydrogen gas. Perhaps all of these aqueous solutions contain the same ion and this ion accounts for the formation of H_2 (g). It is reasonable to propose that the common ion is H^+ (aq). We postulate: a substance has the properties of an acid if it can release hydrogen ions.

Consider the following compounds:

NaOH	: Sodium Hydroxide
KOH	: Potassium Hydroxide
$Mg(Oh)_2$	: Magnesium Hydroxide
Na_2CO_3	: Sodium Carbonate
NH_4	: Ammonia

Each of these five compounds shares the following important properties.

1. *Electrical Conductivity*: Like acids, these compounds dissolve in water to form conducting solutions. Ions are present in an aqueous solution of a base.
2. *Reaction with Acids*: When one of these compounds is added to an acid solution, it destroys the identifying properties of the acid solution—all but electrical conductivity.
3. *Colour of Litmus:* The dye, litmus, is blue in colour when placed in an aqueous solution of any of these compounds.
4. *Taste:* The dilute aqueous solutions taste bitter.
5. *Feel:* The aqueous solutions feel "slippery." Again these properties constitute the simplest definition of base. These properties provide a basis for deciding whether some other compound should be classified as a base.

Definitions

A substance in an acid of it can release hydrogen ion, H^+ (aq).

A substance is a base if it can react with hydrogen ions, H^+ (aq).

The Nature of H^+ (aq)

Both of our explanations of the properties of acids and bases involve the hydrogen ion, H^+ (aq). This species has great impor.ance in the chemistry of aqueous solutions.

Before considering what a chemist means by the symbol H^+ (aq), we must discuss more generally the interaction of ions with water. Lithium chloride provides a good example. Lithium chloride dissolves in water spontaneously at 25°C, forming a conducting solution. At equilibrium, it has a high solubility:

$$\text{Li Cl}(s) \rightleftharpoons \text{Li}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \quad t=25°\text{C} \qquad \ldots (1)$$

Lithium chloride melts spontaneously above 613°C and forms a liquid that conducts electricity.

$$Li\,Cl\,(s) \rightleftharpoons Li^+(1) + Cl^-(1) \quad t=613°\text{C} \qquad \ldots (2)$$

Equilibrium in any reaction is determined by compromise between tendency toward minimum energy and tendency towards maximum randomness. Reactions (1) and (2) both involve increase in randomness since the regular solid lattice dissolves or melts to become part of a disordered liquid state. Both reactions produce ions. But reaction (1) proceeds readily at 25°, whereas reaction (2) does not occur until

the solid is quite hot, 613°C. The difference must be in the special stabilities of Li^+ and Cl^- ions in water. The high melting point of lithium chloride shows that the crystal is very stable. The high solubility of lithium chloride in water can be explained only by saying that Li^+ (aq) and Cl^- (aq) must also be very stable. This means that water must interact strongly with these ions.

A similar situation exists for hydrochloric acid *HCl*. This gaseous compound dissolves readily in water at 25°C:

$$HCl\ (g) \rightleftharpoons H^+\ (aq) + Cl^-\ (aq). \qquad t=25°C \qquad \ldots (3)$$

The *HCl* molecule is a stable one, it must be heated to a few thousand degrees before the atoms will separate. Even then, neutral atoms are obtained and still higher temperatures are needed before gaseous ions are obtained.

$$HCl\ (g) \rightleftharpoons H(g) + Cl(g). \qquad t \text{ very high} \ldots (4)$$

The high temperature required to separate the two atoms of a molecule of *HCl* shows that HCl is very stable. Again we can explain the solubility of HCl in water by saying H^+ (aq) and Cl^- (aq) must also be very stable. Water must interact strongly with these ions.

That is why we have been symbolising these ions as Li^+ (aq), H^+ (aq), and Cl^- (aq). The notation (aq) reminds us that the ions interact strongly with the solvent.

pH:

For compact expression of H^+ (aq) concentrations, chemists use a quantity, defined by the equation.

$$pH = -\log_{10}(H^+)$$

Since $(H^+) = 10^{-7}\ M$ in a neutral solution at 25°C, it follows that for such a solution.

$$pH = -(\log_{10} 10^{-7}) = -(-7) = +7$$

This result helps us to understand the symbol pH, first defined by a Danish chemist, Sorenson. He used the *p* to stand for the Danish word potenz (power) and *H* to stand for hydrogen. After a change of sign, pH is the power of ten needed to express the hydrogen ion concentration in moles per liter. In acidic solutions, *pH* is less than 7 ($pH<7$); and in basic solutions, pH is greater than 7 (pH)>7).

Concentrations of H^+ (aq) and OH^- (aq) Expressed in terms of pH.

Acidity or Basicity	$H+$	*pH*
acidic	1.00	0
acidic	10^{-1}	1
acidic	10^{-2}	2
neutral	10^{-7}	7
basic	10^{-13}	13

Strength of Acids

The strong and weak electrolytes are distinguished in terms of degree to which the dissolved material forms ions. As a particular case, such distinctions can be made in terms of acids, furnishing a quantitative basic for defining the strength of an acid.

Weak Acids

In water, hydrochloric acid dissociates completely to ions, *HCl* is a strong electrolyte. Because one of the ions released is H^+ (aq), *HCl* is also called a *strong acid*. Acetic acid, on the other hand, dissociates to ions only to a slight extent; acetic acid is a weak electrolyte. Because one of the ions released is H^+ (aq), acetic acid is called a *weak acid*.

We can express these ideas in terms of a general acid, *HB*. The acidic nature of *HB* is connected to its ability to release hydrogen ions;

$$HB\ (aq) \rightleftharpoons H^+\ (aq) + B^-\ (aq) \qquad \ldots (4)$$

The equilibrium constant for reaction (4) measures quantitatively the case with which *HB* releases H^+ (aq) ions,

$$KA = \frac{(H^+)\ (B^-)}{(HB)} \qquad \ldots (5)$$

The value of *KA* furnishes a quantitative measure of acid strengths with which we can compare different acids and predict their properties.

TABLE

Relative Strengths of Acids in Aqueous Solution at Room Temperature

$$KA = \frac{(H^+)\ (B^-)}{(HB)}$$

Acid	*Strength*	*Reaction*	*KA*
HCl	Very strong	$HCl\ (g) \rightleftharpoons H^+(aq) + Cl^-(aq)$	Very large
HNO_3	-do-	$HNO_3(g) \rightleftharpoons H^+(aq) + NO_3^-(aq)$	-do-
H_2SO_4	-do-	$H_2SO_4 \rightleftharpoons H^+(aq) + HSO_4^{-2}(aq)$	large
HSO^-_4	Strong	$HSO^-_4(aq) \rightleftharpoons H^+(aq) + SO^{-2}_4(aq)$	1.3×10^{-2}
HF	Weak	$HF(aq) \rightleftharpoons H^+(aq) + F^-(aq)$	6.7×10^{-4}
CH_3COOH	-do-	$CH_3CooH(aq) \rightleftharpoons H^+(aq) + CH_3Coo^-(aq)$	1.8010^{-5}
H_2CO_3 $CO_2 + H_2O$	-do-	$H_2Co_3(aq) \rightleftharpoons H^+(aq) + HCo^{-3}(aq)$	4.4×10^{-7}
H_2S	-do-	$H_2S(aq) \rightleftharpoons H^+(aq) + HS^-(aq)$	1.0×10^{-7}
NH^+_4	-do-	$NH^+_4(aq) \rightleftharpoons H^+(aq) + NH_3(aq)$	5.7×10^{-10}
HCO_3^-	-do-	$HCo_3^-(aq) \rightleftharpoons H^+(aq) + Co_3^{-2}(aq)$	4.7×10^{-11}
H_2O	Very weak	$H_2O(aq)H^+(aq) + OH^-(aq)$	1.8×10^{-16}

Competition for H^+ Among Weak Acids

We have explained the properties of acids in terms of their abilities to release hydrogen ions, $H^+(aq)$. Thus acetic acid is a weak acid because of the slight extent to which reaction (6) releases $H^+(aq)$:

$$CH_3COOH \rightleftharpoons H^+(aq) + CH_3COO^-(aq) \qquad \ldots (6)$$

We have explained the properties of bases in terms of their abilities to react with hydrogen ion. Thus ammonia is a base because it can react as in (7):

$$NH_3(aq) - H^+(aq) \rightleftharpoons NH^+{}_4(aq) \qquad \ldots (7)$$

Now consider the result of mixing aqueous solutions of acetic acid and ammonia. The reaction that occurs can be compared to a sequence of reactions,

$$CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$$
$$NH_3(aq) + H^+(aq) \rightleftharpoons NH^+{}_4(aq)$$

Net reaction

$$CH_3COOH(aq) + NH_3(aq) \rightleftharpoons CH_3COO^-(aq) + NH_4{}^+(aq) \qquad \ldots (8)$$

Practically, the result of reactions (6) and (7) is reaction (8). In reaction (8), we see that acetic acid acts as an acid in the same sense that it does in (6). In either case, it releases hydrogen ions. In (6) acetic acid releases hydrogen ions and forms $H^+(aq)$ and in (8) it releases hydrogen ions to NH_3 and forms $NH_4{}^+$. In the same way, ammonia acts as a base in (8) by reacting with hydrogen ion released by acetic acid. So reaction (8) is an acid-base reaction, though the net reaction does not show $H^+(aq)$ explicitly.

Now by taking one more step we can view acid base reaction in a broader sense. Suppose we mix aqueous solution of ammonium chloride, NH_4Cl, and sodium acetate, CH_3COONa. A sniff indicates ammonia has been formed.

Reaction occurs,

$$NH_4{}^+(aq) + CH_3COO^-(aq) \rightleftharpoons CH_3COOH(aq) + NH_3(aq) \quad \ldots (9)$$

Reaction (9) is just the reverse of reaction (8). Inspection of this reaction reveals that reaction (9), too, is an *acid base reaction*. Once again there is an acid that releases H^+— it is $NH_4{}^+$—and a base that accepts H^+—the base is CH_3COO^-. Once again the net effect of the reaction is transfer of a hydrogen ion from one species to another. We see that the acid-base reaction between acetic acid and ammonia gave two products, one an acid, $NH_4{}^+$ and one a base, CH_2COO^-. A little thought will convince you that *every* acid-base reaction does so. The transfer of a hydrogen ion from an acid to a base necessarily implies that it might be handed back. The reaction of handing it back, the reverse reaction, is just as much a hydrogen ion transfer, hence an acid-base reaction, as is the original transfer.

Notice that we are now referring to reaction in which a hydrogen

ion is transferred from an acid to a base without specifically involving the aqueous species $H^+(aq)$. A hydrogen ion, H^+, is nothing more than a proton. Consequently we can frame a more general view of acid-base reaction in terms of proton transfer. The main value of this view is that it is applicable to a wider range of chemical systems, including non-aqueous systems.

We can generalise our view of the acid-base type of reaction as follows. In our example, reaction (8).

$$\underset{\text{an acid}}{CH_3COOH} + \underset{\text{a base}}{NH_3} \rightleftharpoons \underset{\text{an acid}}{NH_4^+} \; \underset{\text{a base}}{CH_3COO^-} \qquad \ldots (8)$$

The acetic acid reacts as an acid, giving up its proton, to form acetate, CH_3COO^-, a substance that can act as a base. We can write (8) in a general form:

$$HB_1 + B_2 \rightleftharpoons HB_2 + B_1 \qquad \ldots (10)$$

$$Acid_1 + Base_2 \quad Acid_2 + Base_1 \qquad \ldots (11)$$

We see that an acid and a base react, through proton transfer, to form another acid and another base.

We can use this more general view to discuss the strength of acids. In our generalised acid-base reaction (10) the proton transfer implies the chemical bond in HB_1 must be broken and the chemical bond in HB_2 must be formed. If the HB_1 bond is easily broken, then HB, will be a strong acid. Then equilibrium will tend to favour a proton transfer from HB_1 to some other base, B_2. If, on the other hand, the HB_1 bond is extremely stable, then this substance will be a weak acid. Equilibrium will tend to favour a proton transfer from some other acid, HB_2 to base B_1, forming the stable HB_1 bond.

Hydronium Ion in the Proton Transfer Theory of Acids

In the proton transfer view of acid base reactions an acid and a base react to form another acid and another base. Let us see how this theory encompasses the elementary reaction between $H^+(aq)$ and $OH^-(aq)$ and the reaction of dissociation of acetic acid, reactions (12) and (13):

$$H^+(aq) + OH^-(aq) \rightleftharpoons H_2 \qquad \ldots (12)$$

$$CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq) \qquad \ldots (13)$$

It does so by making a specific assumption about the nature of the species $H^+(aq)$. It is considered to have the molecular formula H_3O^+ (aq). Thus, when NCl dissolves in water, the reaction is written.

$$HCl(g) + H_2O \rightleftharpoons H_3O^+(aq) + Cl^-(aq) \qquad \ldots (14)$$

instead of

$$HCl(g) \rightleftharpoons H^+(aq) + Cl^-(aq) \qquad \ldots (15)$$

Whenever $H^+(aq)$ might appear in an equation for a reaction, it is replaced by the hydronium ion, H_3O^+, and a molecule of water is added to the other side of the equation. We write (13) in the form.

$$CH_3COOH(aq)+H_2O \rightleftharpoons H_3O(aq)+CH_3COO^-(aq) \qquad ...(16)$$

Now the dissociation of acetic acid can be regarded as an acid-base react on. The acid CH_3COOH transfers a proton to the base H_2O forming the acid H_3O t and base CH_3COO^-.

The reaction (12) now takes the form:

$$H_3O^+(aq)+OH^-(aq) \rightleftharpoons H_2O+H_2O \qquad ...(17)$$

In (17) the acid H_3O^+ transfers a proton to the base OH^- forming an acid, H_2O, and a base, H_2O. We see that within the proton transfer theory, the molecule H_2O must be assigned the properties of an acid, and, as well, those of a base.

Contrast of Acid Base Definitions

Definition 1: An acid is a substance that has the properties listed b elow when dissolved in water:

It is an electrical conductor;
It reacts with Zn to give $H_2(g)$;
It makes litmus red;
It tastes sour.

Definition 2: An acid is a substance that can release protons.

The first definition is one of the type called an "operational definition". An operation definition is, then a definition that lists, as criteria, measurements and observations (that is, operations) by which you could decide whether a given object is "in" or "out".

The second definition is a "conceptual definition". It defines the class in terms of an explanation of why the class has its properties.

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OXIDATION-REDUCTION REACTIONS

Electrochemical Cells

Electrochemical cells are familiar—a flashlight operates on current drawn from electrochemical cells called dry cells, and automobiles are started with the aid of a battery, a set of electrochemical cells. Why does electric current flow from a new dry cell but not from one that has been for used many hours? We shall see that this is an important question in chemistry. By studying the chemical reactions that occur in an electrochemical cell we discover a basis for predicting whether equalibrium in a chemical reaction favours reactants or products. The reactions of this type are called oxidation-reduction reactions.

The Chemistry of an Electrochemical Cell

Let us begin our investigation of an electrochemical cell by assembling one. Fill a beaker with a dilute solution of silver nitrate (about 0.1 m will do) and another beaker with dilute copper sulphate. With a wire connect the silver rod to one terminal of an ammeter to measure the electric current. Connect the other terminal of the ammeter through a wire resistance, *R*, to the copper rod. Finally connect the two solutions to complete the circuit. A glass tube containing sodium nitrate solution furnishes an electrical path. It is called a self bridge.

As soon as the last connection is made, things start to happen. The ammeter needle deflects – electric current is moving through the meter and resistance, *R*. The direction of current flow is that of electrons moving from the copper rod to the silver rod. The resistance becomes warm – the cell is doing work as it forces electrons through *R*. In the beakers, the copper rod dissolves and the silver rod grows As time goes by, the ammeter shows less and less current flow until, finally, there is none.

One mole of copper dissolves for energy two moles of silver. Copper ions $Cu^{+2}(aq)$, are formed in the right beaker from the neutral copper metal atoms. This means atoms of copper release electrons into the copper rod. These electrons move into the wire, through the resistance and through the ammeter. They arrive at the silver rod in the left

beaker, where silver metal is formed from silver ions, Ag^+ (aq). Here, the positive silver ions draw electrons from the silver rod to become neutral silver metal atoms.

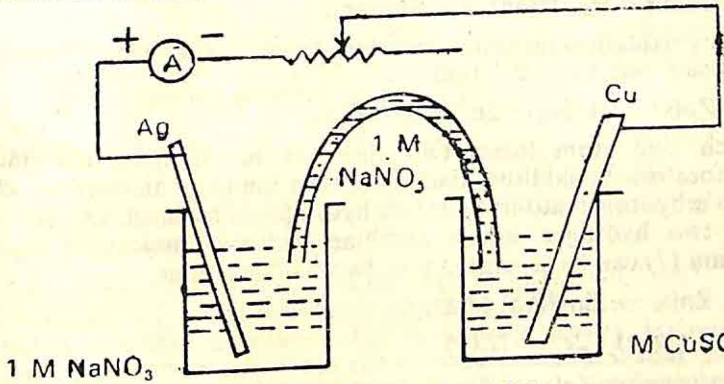


Fig. 16.1 An Electrochemical Cell

In the right beaker,
$Cu(s) \rightarrow Cu^{+2}(aq) + 2e^-$ . . . (1)

In the left beaker,
$2Ag^+(aq) + 2e^- \rightarrow 2Ag(s)$ . . . (2)

Overall reaction,
$Cu(s) + 2Ag^+(aq) \rightarrow 2Ag(s) + Cu^{+2}(aq)$ . . . (3)

Reactions (1) and (2) are called half cell reactions or half reactions. The net reaction (3) is obtained by combining (1) and (2) so as to cause the exact balancing of electrons lost by copper atoms, in (1), and electrons gained by silver ion, in (2). The cancellation is necessary because electrical measurements show that the electrochemical cell operates without accumulation or consumption of electric charge. The reaction mixture always remains electrically neutral. The number of electrons lost equals the number of electrons gained.

We see that the overall chemical reaction that occurs in an electrochemical cell is conveniently described in terms of two types of half-reactions. In one, electrons are lost; in the other, they are gained. To distinguish these half-reactions we need two identifying names.

The half-reactions in which electrons are lost is called oxidation.

Oxidation $Cu(s) \rightarrow Cu^{+2}(aq) + 2e^-$ . . . (4)

The half-reaction in which electrons are gained is called reduction.

Reduction $2Ag^+(aq) + 2e^- \rightarrow 2Ag(s)$ . . . (5)

The overall reaction is called an oxidation-reduction reaction.

Oxidation-reduction reaction

$Cu(s) + 2Ag^+(aq) \rightarrow Cu^{+2}(aq) + 2Ag(s)$ . . . (6)

It is often convenient and usually informative to treat oxidation-reduction in terms of half-reactions.

Zinc Oxidised by $H^+(aq)$ in a Beaker

Many oxidation-reduction reactions (nicknamed "redox" reactions) take place inaqueous solution.

$$Zn(s) + 2H^+(aq) — 2n^+2(aq) + H_2(g) \quad \ldots (7)$$

Each zinc atom losses two electrons in changing to a zinc ion, therefore zinc is oxidised. Each hydrogen ion gains an electron, changing to a hydrogen atom, therefore hydrogen is reduced. (After reduction, two hydrogen atoms combine to form molecular H_2.) The reaction (7) can be separated into two half-reactions.

$$Zn(s) \rightarrow Zn^{+2}(aq) + 2e^- \quad \ldots (8)$$

$$\underline{2H^+(aq) + 2e^- \rightarrow H_3(g)} \quad \ldots (9)$$

$$\text{Net reaction } Zn(s) + 2H^+ \rightarrow Zn^{+2} + H_2(g) \quad \ldots (10)$$

Thus the reaction by which a metal dissolves in an acid is conveniently discussed in terms of oxidation and reduction involving electrons transfer. The reaction can be divided into half-reactions to show ths electrons gain (by H^+ ions) and the electron loss (by metal atoms).

Not all metals react with aqueous acids. Among the common metals, magnesium, aluminium, iron, and nickel liberate H_2 as zinc does other metals, including copper, mercury, silver and gold, do not produce measurable amount of hydrogen even though we make sure that the equilibrium state has been attained.

Zinc Oxidised by $Cu^{+2}(aq)$ in a Beaker

As a third oxidation-reduction example, suppose a strip of metallic zinc is placed in a solution of copper nitrate, $Cu(NO_3)_2$ contained in a beaker. The strip becomes coated with reddish metallic copper and the bluish colour of the solution disappears. The presence of zinc ion, Zn^{+2}, among the products can be shown when the Cu^{+2} colour is gone. Then if hydrogen sulphide gas is passed into the mixture, white zinc sulphide, Zn S can be seen. The reaction between metallic Zn and the aqueous copper nitrate is

$$Zn(s) + Cu^{+2} \rightarrow Zn^{+2} + Cu(s) \quad \ldots (11)$$

Zinc has last electrons in reaction (11) to form Zn^{+2}!

$$Zn(s) \rightarrow Zn^{+2} + 2e^- \quad \ldots (12)$$

Zinc is oxidised. If zinc is oxidised, releasing electrons, something must be reduced accepting electrons-copper ion is reduced.

$$Cu^{+2} + 2e^- \rightarrow Cu(s) \quad \ldots (13)$$

This time, copper ion gains electrons from zinc in contrast to the behaviour where metal lost electrons to silver.

What about the state of equilibrium for the reaction represented by equation (11)? Let us place a strip of metallic copper in a zinc sulphate solution. No visible reaction occurs and attempts to detect the presence of cupric ion by adding H_2S to produce black colour of cupric sulphide, CuS, fail. Cupric sulphide has such low solubility that this is an extremely sensitive test yet the amount of Cu^{+2} formed cannot be detected. Apparently the state of equilibrium for the reaction (11) greatly favours the products over the reactants.

Competition for Electrons

These reactions can be viewed as a competition between two kinds of atoms (or molecules) for electrons. Equilibrium is attained when this competition reaches a balance between opposing reactions.

In case of the reaction, $Cu(s)+2Ag^{+}(aq)\rightarrow 2Ag(s)+Cu^{+2}(aq)$ copper metal reacting with silver nitrate solution, the Cu(s) releases electrons and Ag^{+} accepts them so readily that equilibrium greatly favours the products, Cu^{+2} and Ag(s). Since randomness tends to favour neither reactants nor products, the equilibrium must favour products because the energy is lowered as the electrons are transferred. If we regard the above reaction as a competition between silver and copper for electrons, stability favours—silver over copper.

The same sort of competition for electrons is involved in reaction (11), in which Zn(s) releases electrons and Cu^{+2} accepts them. This time the competition for electrons is such that equilibrium favours Zn^{+2} and Cu(s).

Since zinc releases electrons to copper ion, we know that we must add it to our list at the top:

$$Zn(s) \quad — \quad Zn^{+2}+2e^-$$
$$Cu(s) \quad — \quad Cu^{+2}+2e^-$$
$$Ag(s) \quad — \quad Ag^{+}+e^-$$

Listing the $Zn\text{-}Zn^{+2}$ half reaction first tells us that it releases electrons more readily than does $Cu\text{-}Cu^{+2}$ half-reaction. But if this is true, then the $Zn\text{-}Zn^{+2}$ half-reaction must also release electrons more readily than does $Ag\text{-}Ag^{+1}$ half-reaction. The list leads us to expect that zinc metal will release electrons to silver ion, reacting to produce zinc ion and silver metal.

We should test this proposal. We dip a piece of zinc metal in a solution of silver nitrate. The result confirms our expectation; zinc metal dissolves and bright crystal of metallic silver appears.

Our data allow us to make one more addition to the list. By reaction (7), zinc reacts with H+ to give Zn^{+2} and $H_2(g)$. The half-reaction $H_2\text{-}2H^+$ must be placed below the $Zn\text{-}Zn^{+2}$ half reaction. How far below? To answer that, remember that copper does not react with H^+ to produce H_2. This indicates that the half-reaction $H_2\text{-}2H^+$

releases electrons more readily than does the half-reaction Cu-Cu^{+2}. Now we can expand our list in the following manner.

Some Half-reactions listed in order of tendency to release electrons

Zn(s)	→	$Zn^{+2}+2e^-$
H_2(g)	→	$2H^++2e^-$
Cu(s)	→	Cu^++2e^-
Ag(s)	→	Ag^++e^-

Electron Transfer and Predicting Reactions

The usefulness of the list is clear. Quantitative predictions of reactions can be made with the aid of the ordered list of half-reactions. Think how the value of the list would be magnified if we had a quantitative measure of electrons losing tendencies. The voltages of electrochemical cells furnish such—quantitative measure.

Electron Losing Tendency

The circuit in Fig. 16.1 includes a wire resistance coil, *R*. As the current flows through *R*, heat is generated. The cell is doing electrical work in forcing the electron current through *R*. Again we apply the law of conservation of energy. As the electrons leave *R*, they must have lower potential energy than they had when they entered. As they fall to lower potential energy, the energy change appears as heat. This potential energy change is measured by voltage. Just as lowering a mass from higher altitude decreases its potential energy, moving an electric charge to a lower voltage lowers its potential energy.

So the voltage of an electrochemical cell measures its capacity for doing electrical work. Different cells show different voltages.

Oxidation Numbers

An Electron book-keeping device: The reaction between ferric ion, Fe^{+3}, and cuprous ion, Cu^+, to produce ferrous ion, Fe^{+2} and cupric ion, Cu^{+2} is plainly on oxidation-reduction reaction:

$$Fe^3+Cu^+ \rightarrow Fe^{+2}+Cu^{+2} \quad \ldots (16)$$

It is readily separated into two half-reactions showing electron transfer:

Oxidation (loss of electrons) $Cu^+ \rightarrow Cu^{+2}+e^-$ . . . (17)
Reduction (gain of electrons) $Fe^{+3}+e^- \rightarrow Fe^{+2}$ . . . (18)

Because of the presence of Cu^+ ion, ferric ion is reduced. Chemists say that Cu^+ ion acts as a reducing agent in this reaction —Cu^+ ion is the "agent" that caused the reduction of ferric ion. At the same time, Cu^+ is oxidised because of the presence of ferric ion.

Hence, Fe^{+3} is called an oxidising agent in this reaction.

Another reaction by which ferric ion can be reduced involves bisulphite ion, HSO_3^-. The balance equation is:

$$H_2O + HSO_3 + 2Fe^{+3} \rightarrow 2Fe^{+2} + HSO_4^- + 2H^+ \quad \ldots (19)$$

Again half-reaction $Fe^{+3} + e^- \rightarrow Fe^{+2}$ describes what happens to ferric ion:

$$2Fe^{+3} + 2e^- \rightarrow 2Fe^{+2} \quad \ldots (20)$$

Since two electrons are gained by the two ferric ions in half-reaction (20), two electrons must be released by the remaining constituents in (19). The other half reaction can be found by sub-tracting (20) from (19) to give:

$$H_2O + HSO_3 - 2e^- \rightarrow HSO_4 + 2H^+$$

or

$$H_2O + HSO^-_3 \rightarrow HSO_4^- + 2H^+ + 2e^- \quad \ldots (21)$$

The combination of H_2O and HSO^-_3 acts as a reducing agent toward Fe^{+3}. Since water solutions of Fe^{+3} are quite stable, HSO_3- is considered to be the actual reducing agent.

Half-reaction (21) differs from the others we have looked at.

Since we don't know the locations of the electrons held by a molecule such as HSO_3-, we assume that the hydrogen atom has a $+1$ charge, that each oxygen atom has a -2 charge, and that the sulphur atom has all the rest of the electrons in the molecule. Of course, if the charges on all the atoms in HSO_3^- are added together, they must sum to -1, the molecular charge. Since there are three oxygen atoms in HSO_3^-, the algebra looks like this:

$$\begin{pmatrix}\text{Charge on}\\ \text{hydrogen}\\ \text{atom}\end{pmatrix} + 3\begin{pmatrix}\text{Charge on}\\ \text{oxygen}\\ \text{atom}\end{pmatrix} + \begin{pmatrix}\text{Charge on}\\ \text{sulphur}\\ \text{atom}\end{pmatrix} = \begin{pmatrix}\text{Mole-}\\ \text{cular}\\ \text{charge}\end{pmatrix}$$

$$\underset{\text{assumed}}{(+1)} + \underset{\text{assumed}}{3\,(-2)} + \begin{pmatrix}\text{Charge on}\\ \text{sulphur}\\ \text{atom}\end{pmatrix} = -1$$

$$(\text{Charge on sulphur atom}) = (+4)$$

This fictitious charge is called the *oxidation number* of sulphur.

Oxidation number of sulphur $= +4$ in HSO_3^-.

The same process can be applied to HSO_4^-. Again assuming hydrogen has a charge of $+1$ and each of the four oxygen atom has a charge of $+12$, we calculate a fictitious charge on the sulphur atom of $+6$.

Oxidation number sulphur $= +6$ in HSO_4^-. According to the oxidation number book-keeping, the two electrons released in the HSO_3^-—HSO_4^- half-reaction (21) are associated with the charge in oxidation number of sulphur from $+4$ to $+6$.

Sulphur forms two oxides, SO_2 (a gas at normal conditions) and SO_3 (a liquid that boils at 44.8°C). Under suitable conditions, SO_2 reacts with oxygen to form SO_3:

$$2SO_2(g)+O_2(g)\rightarrow 2SO_3(g) \qquad \ldots (22)$$

In SO_2:

$$2\begin{pmatrix}\text{Charge on}\\ \text{oxygen}\\ \text{atom}\end{pmatrix}+\begin{pmatrix}\text{Charge on}\\ \text{sulphur}\\ \text{atom}\end{pmatrix}=\begin{pmatrix}\text{Molecular}\\ \text{charge}\end{pmatrix}$$

$$2\,(-2)+(\text{Oxidation})=(0)$$
assumed number
sulphur

Oxidation number sulphur $=+4$ in SO_2

In SO_3:

$$3\begin{pmatrix}\text{Charge on}\\ \text{oxygen}\\ \text{atom}\end{pmatrix}+\begin{pmatrix}\text{Charge on}\\ \text{sulphur}\\ \text{atom}\end{pmatrix}=\begin{pmatrix}\text{Molecular}\\ \text{charge}\end{pmatrix}$$

$$3\,(-2)+\begin{pmatrix}\text{Oxidation}\\ \text{number}\\ \text{sulphur}\end{pmatrix}=(0)$$

Oxidation number sulphur $=+6$ in SO_3. Thus in reaction (22) the sulphur atom changes oxidation number from $+4$ to $+6$ m just as it did in the HSO_3^-—HSO_4^- half-reaction. The oxidation number gives a basis for connecting the SO^-_2 SO_3 change to the oxidation of HSO^-_3 to HSO_4^-. Both charges are considered to be examples of oxidation.

Oxidation-reduction reactions occurring in aqueous solutions are conveniently treated in terms of half-reactions showing transfer of electrons. Under more general conditions (gaseous state, other solvents, etc.,) it is more convenient to treat oxidation-reduction reactions in terms of oxidation numbers, based upon the arbitrary scheme of assigning charge $+1$ to a hydrogen atom bound to an unlike atom and charge -2 to an oxygen atom when it is bound to unlike atoms. Generally, then, an *oxidation-reduction reaction* is one in which oxidation numbers change.

Use of Oxidation Number of Balancing Oxidation-Reduction Reactions:

We have talked above oxidation numbers as a device for assigning a fictitious charge to an atom in a molecule. According to this scheme, oxidation-reduction reactions involve changes of oxidation numbers. Consideration of conservation of charge reveals that there must be a balance between changes of oxidation number. Consequently, oxidation numbers provide a good basis for balancing equations.

The rules[1] we will utilise are as follows:

(1) The oxidation number of mono-atomic ion is equal to the charge on the ion.

(2) The oxidation number of any substance in the elementary state is zero.

(3) The oxidation number of hydrogen is taken to be +1 (except in H_2, which is the elementary state.)

(4) The oxidation number of oxygen is taken to be —2 (except in O_2; ozone; O_3; and peroxides).

(5) The other oxidation numbers are selected to make the sum of the oxidation numbers equal to the charge on the molecule.

(6) Reactions occur such that the net change of oxidation numbers in zero. (This rule is really a result of the conservation of charge).

EXAMPLE

We want to balance the equation for reaction that occurs when H_2S gas is bubbled into an acidified potassium permanganate solution. When we do this, we observe that purple colour of the MnO_4^- ion disappears and the resulting mixture is cloudy (Sulphur particles). We find H_2S gas reacts with MnO^-_4 to give solid sulphur and Mn^{+2}.

$$MnO_4^- + H_2S(g) \text{ gives } S(s) + Mn^{+2}$$

First, we assign oxidation numbers to each element, using rules 1 to 5 we find:

$MnO_4^- + H_2S(g)$	$S(s) + Mn^{+2}$	
$+7 \quad -2$	$0 + 2$	(oxidation number)

With changes,

for manganese $+7 \quad -5 \longrightarrow +2$

for sulphur $\quad -2 \rightarrow 0$

$\qquad +2$

If the gain in oxidation number by sulphur is to equal the loss by manganese, then five atoms must react with two atoms of manganese:

$$2MnO_4^- + 5H_2S(g) \text{ gives } 5S(s) + 2Mn^{+2} \quad \ldots (23)$$

(not balanced)

$$2(+7) \; \frac{2(-5) = -10}{5(-2) \rightarrow 5(0)} \; 2(+2)$$

$$5(+2) = +10$$

Now we proceed to ensure conservation of oxygen atoms. There are eight oxygen atoms on the left in (23), hence we must add eight

1. *Chemistry—An Experimental Science*, edited by George C. Pimental, Indian Ed., 1964, N.C.E.R.T., New Delhi.

molecules of H_2O to the right. (The reaction occurs in aqueous solution, so there is plenty of H_2O).

$2MnO_4 + 5H_2S(g)$ gives $5S(s) + 2Mn^{+2} + 8H_2(O)$ not balanced next we must ensure conservation of hydrogen atoms. On the left, are 10 hydrogen atoms (in $5H_2S$) on the right 16 (in $8H_2O$). In aqueous solution, (in neutral or acidic solution) we assume that there six hydrogen atoms needed on the left are provided by H^+:

$$2MnO_4 + 5H_2S(g) + 6H^+ \rightarrow 5S(s) + 2Mn^{+2} + 8H_2O$$

The equation is balanced now but experience dictates that a check should always be made on the basis of charge balance:

$$\begin{array}{ccc} 2(-1)+5(0)+6(+1) & = & 5(0)+2(+2)+8(0) \\ -2 \quad +6 & = & +4 \\ +4 & = & +4 \end{array}$$

22

CHEMICAL BONDS

Why and How do Atoms Combine to form Molecules

If we could answer this question, we hope to be able to account for the many properties of elements and compounds. Even before the structure of the atom was established, chemists tried to answer this question and that is how the concept of valence originated.

The valence of carbon is four and that of chlorine is one really explains nothing. It simply reflects the fact that carbon tetrachloride has the formula CCl_4. But we want to know why this formula is CCl_4. Besides, there are other properties of this compound which need an explanation. For example, why does carbon tetrachloride not conduct electricity? Why it has low boiling? Why does the molecule have its special shape?

We can answer these questions in the light of the electronic structures of atoms. For this we require an understanding of the nature of Chemical Bonds.

Problem s

When a stream of hydrogen gas from Kipp's apparatus is passed througn an acidified solution of potassium permanganate, no colour change occurs. However, if a piece of zinc is added to the solution, the colour disappears. Hydrogen gas from Kipp's apparatus is not able to reduce the potassium permanganate, whereas the hydrogen produced in the solution by the reection between zinc and the acid reduces. In what way is the latter sample of hydrogen different and more reactive?

The hydrogen, chlorine and oxygen are diatomic molecules. Why do the atoms in these molecules prefer this arrangement? Why are the molecules diatomic? Could their atomicity be higher than two? Such questions lead us to concentrate on why and how atoms combine?

It is an experimental fact that 103.4 K cals of energy is required to separate hydrogen atoms from a mole of hydrogen molecules. And when atoms combine to form molecules, energy will be released and thus there will be lowering of energy with the formation of molecules. This means that the molecules are more stable than the separated

atoms from which they are obtained. When this lowering energy exceeds 10 K cal/mole, the molecular structure have distinct and

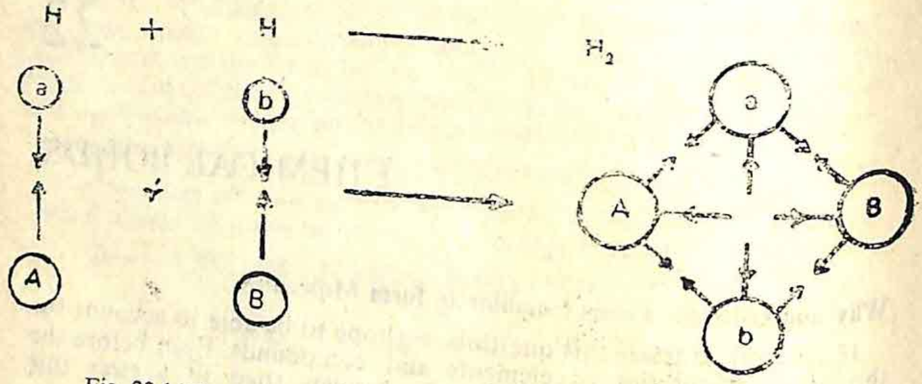


Fig. 22.1 Interaction between two approaching Hydrogen Atoms.

characteristic chemical properties different from those of separated atoms. We then say that chemical bonds are formed, between the atoms involved. Therefore, whenever a chemical bond is formed between two atoms, there will be a lowering of energy.

Why does lowering of energy occur when a chemical bond is formed? Let us try to understand what happens when two atoms of hydrogen approach each other. Each atom of hydrogen contains a proton in the nucleus and an electron in the orbit of the atom. Which force bonds the electron to the atom?

When the atoms are close to each other, the electron 'a' and 'b' is attracted by both the nuclei 'A' and 'B'. Neither of the electrons is, therefore, attracted exclusively by one nucleus. The chemical bond in H_2 is formed because each of the two electrons is attracted simultaneously by two nuclei and this is the force that holds the two atoms together. Since the two electrons are simultaneously attracted by both the nucleus they are shared by them. A bond which arises due to the sharing of two electrons by two atoms is called a *co-valent bond.*

You may wonder why such a simultaneous attraction of the electrons by two nuclei should result in a low energy state. You should recall the force that binds an electron to an atom. But the fact that the nucleus exerts a force of attraction on the electron, the electron would fly away from the atom. It is the force of attraction which determines the energy of an electron in an atom and hence the energy of the atom itself. The greater the force of attraction the lesser the energy. Recall that a 2_s electron is in a higher energy state than 1_s electron. When two nuclei simultaneously exert an attraction on an electron, there is a considerable increase in the strength of this force. Hence these will be a lowering of energy resulting in a more stable arrangement than the separated atoms. A chemical bond is formed if this is possible.

Is this lowering of energy always possible? Why does not a bond form when two helium atoms are brought together? Surely, as in the case of hydrogen, the two helium nuclei should be able to exert attraction on the electrons of both the atoms. Why then do they not bind the helium atoms together to give the molecule He_4?

We seem to have overemphasised the role of attractive forces. We have not looked at the forces of repulsion.

Following are the attractive and repulsive forces between two approaching hydrogen atoms:

Attractive forces that operate between:

1. The nucleus of one hydrogen atom and its own electron.
2. The nucleus of one hydrogen atom and the electron of the other.

Repulsive forces operate between:

1. The electron of one hydrogen atom and that of the other.
2. The nucleus of one hydrogen atom and that of the other.

Which of these forces dominate when the atoms are far apart? When new forces come into operation? When the atoms come close to each other? Since the attractive and repulsive forces between the charged particles increase with decreasing distance, the forces between the nucleus and the electron of one atom and those of the other become significant only when the two atoms are close to each other.

While an increase of attractive forces decrease the energy of a system, an increase of repulsive forces tends to increase the energy. Whether a bond is formed or not when two atoms approach each other depends on whether the forces of attraction and those of repulsion play a dominant role. Since no bond is formed between the helium atoms, it is obvious that the forces of repulsion are too strong to keep the helium atoms together.

But the forces of repulsion firstly, between the two electrons and secondly, between the two nuclei are present even in case of the hydrogen molecule. They tend to increase as the distance between the atoms decreases. Since this increases the potential energy, the atoms cannot come very close to each other. The potential energy will be a minimum, when the two nuclei are at a certain distance. This distance is called the *equilibrium bond length* or *simply bond length*. This is an important property of bonds, which is experimentally measurable.

Use of Orbital Model of the Atom to Explain Bonding

An orbital can accommodate a maximum of two electrons, according to Pauli Exclusion Principle. It can contain just one electron or it could be empty. Each hydrogen atom contains one electron in the lt orbital. When the two hydrogen atoms combine, the two 1_s orbitals overlap. In the region of the overlap, the two electrons are strongly

attracted by both the protons. As a consequence of this, each hydrogen atom appears to have acquired two electrons in the 1_s orbital.

What would you expect if the orbitals already contained two electrons? According to Pauli Exclusion Principle, such an orbital cannot accommodate any more electrons and, therefore, cannot participate in orbital overlap. Therefore bonding does not occur. This is the situation in case of Helium.

You can, therefore, conclude that when a co-valent bond is formed, two partially filled orbitals of the atoms over lap such that two electrons mostly reside in a region when they are simultaneously attracted by the two nuclei.

How is the co-valent bond represented?

1. The hydrogen molecule can be written as H-H. The line between the symbols of the two atoms represents a co-valent bond and indicates that the two electrons are shared by the two atoms. A single line represents one electron pair and also a single bond.

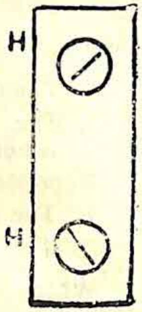


Fig. 22.2

2. *Orbital representation of hydrogen molecule*

   This is to show that the electrons in the overlapping orbits are of opposite spin. Therefore, when a co-valent bond forms electrons of opposite spin get paired.

3. *The electron dot representation is shown as follows:*

The electron in the valence orbital is shown by a dot on each atom and the pair of electrons in the bond is shown between the atoms.

$$H. + .H \rightarrow H:H$$

Similarly, the representation of HF molecule can be done in the above three ways as shown in the following figure (page 215).

You should observe that the 1_s electrons of fluorine are omitted in the dot representation for HF. It is not merely for want of space. When a chemical reaction occurs it is only the electrons in the highest energy levels of the atoms that are involved in bonding because they are, the most loosely bound to nuclei. These are called *valence electrons*. The orbitals they occupy are called valence orbitals. The 2_s and 2_p orbitals are the valence orbitals of the fluorine atom.

How Many Bonds can an Atom Form?

In the examples we talked about in this lesson, each of the combining atoms are co-valent bond and the resulting molecules have formulas like H_2, F_2, HF and Cl_2. Can these atoms form more bonds giving molecules like H_3, F_3 and HF_2.? Experiments tell us that these formulas are not possible. What then determines the number of bonds

an atom can form? Chemists call the number of bonds an atom can form as the bonding capacity of an atom.

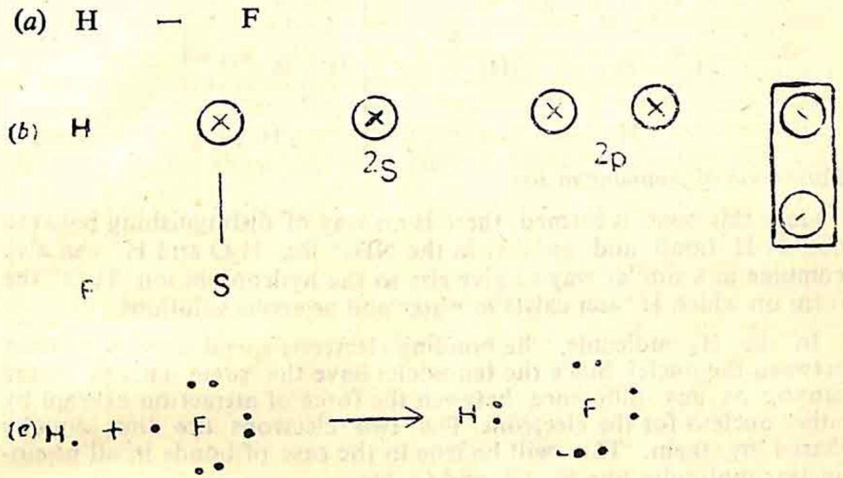


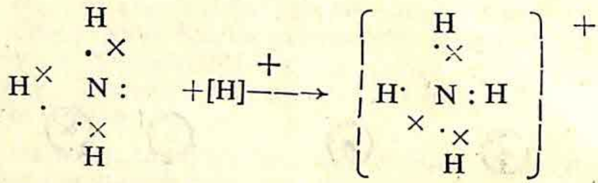
Fig. 22.3

We must seek an answer to this question again in the structure of the atom. The orbital representation of the bonding in F_2 has been used to show that the bond is formed by the overlap of the partially filled 2_p orbitals of the two fluorine atoms. The other valence orbitals already have their quota of two electrons. The example of Helium shows that two orbitals both of which contain two electrons cannot overlap and cannot help in bond formation. Therefore, only the partially filled valence orbitals can be used in bond formation. Fluorine atom has one such orbital and it forms one bond.

So far we have seen that each of the bonded atoms provides an electron for sharing. But there are cases where both the electrons used for sharing belong to one of the atoms before bonding.

For instance, in H^+ ion there is a vacant 1_s orbital on the hydrogen. In NH_3, on the other hand, there is a pair of electrons on the nitrogen atom which has not been used for bonding. When these two species approach each other, there can be an overlap between the vacant valence orbitals of hydrogen and the orbitals of nitrogen containing the pair of electrons not used for bonding. Such bonds are called *co-ordinate co-valent bonds*. This is also a co-valent bond, but both the shared electrons for bond formation originally belonged to the nitrogen atom. In such bonds, the species donating a pair of electrons is called the *donor* and the species which receives the electron pair is

called the *acceptor*. In the above example, the nitrogen atom is the donor and the hydrogen ion the acceptor.



Formation of Ammonium Ion

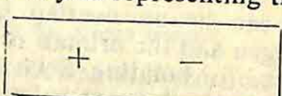
Once this bond is formed, there is no way of distinguishing between one N-H bond and another in the NH_4^+ ion. H_2O and H^+ can also combine in a similar way to give rise to the hydronium ion , H_3O^+ the form on which H^+ ion exists in water and aqueous solutions.

In the H_2 molecule, the bonding electrons spend most their time between the nuclei. Since the ten nuclei have the same charge, there cannot be any difference between the force of attraction exerted by either nucleus for the electrons. The two electrons are thus equally shared by them. This will be true in the case of bonds in all homonuclear molecules like F_2, Cl_2 and O_2 etc.

What happens, if the two bonded atoms are different as in the case of HF? The two electrons spend most of their time between the nuclei of hydrogen and fluorine but the nuclei differ in their abilities to attract the electrons. (Why?). A measure of the ability of an atom to attract electron in a bond is the electronegativity of that atom. Fluorine has a higher electronegativity (4·0) than hydrogen (2·1). Therefore, fluorine has a greater attraction for the electrons than hydrogen. Hence, the bonded electrons, and more likely to be found nearer the fluorine atom, than the hydrogen atom. They are thus not equally shared in a heteronuclear molecules like HF, HCl, H_2O, etc.

This kind of sharing has an interesting consequence. Hydrogen becomes the poorer partner for the electrons in the bond. This makes the hydrogen and of the molecule acquire a partial positive charge. There is thus an unsymmetrical distribution of charge in such molecules. Such molecules are called *polar molecules* and bonds in them are called polar co-valent bonds.

The bonds in which there is a charge separation are supposed to be electric dipoles. One way of representing the dipole:



How Can We Explain Bonding in Compounds like NaCl?

Our model of the polar co-valent bond was based on the fact that one of the bonded atoms has a higher electronegativity than the other.

If the difference in electronegativity is very large, the pair of electrons may get completely attached to the more electronegative atom, converting it into a negatively charged ion. The other atom consequently becomes a positively charged ion. This ion subsequently get strongly bounded to one another because of the strong electrostatic force of attraction between the oppositely charged ions. Bonds between such ions are called *ionic* or *electrovalent bonds*. Compounds which contain electrovalent bonds must be made up of ions. One of the evidences for the existence of ions is conduction of electricity by these compounds in their fused state. Fused NaCl conducts electriticy. Spectroscopic and X-ray studies show that solid NaCl is made up of Na^+ and Cl^- ions.

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CONCEPTS USED IN TEACHING OF PHYSICAL SCIENCES

It is basically needed that every science teacher should have clarity about the concepts for successful teaching of Physical Sciences. These concepts are essentially the foundations upon which the knowledge of Physical Sciences rests and can further be developed. The concepts used in the teaching of Physical Sciences have been discussed in this paper. These concepts have been classified and discussed in the following categories:

(*i*) Length, mass, time.
(*ii*) Velocity, acceleration, force.
(*iii*) Impulse, momentum.
(*iv*) Work, energy.
(*v*) Conservation laws.
(*vi*) Field, potential.
(*vii*) Maxwell Equations.
(*viii*) Electromagnetic Spectrum.

All measurements of the physical world can be expressed in terms of three fundamental quantities: length, mass, and time. The standard unit of length is the meter, the distance between marks on a metal bar preserved by the French Bureau of Standards, and all other meter scales are ultimately calibrated by means of the prototype meter. A direct measurement of the length of an object is made by the operational procedure of setting a calibrated scale along the object and reading off the appropriate subdivision.

The standard unit of mass is the mass of a metal cylinder preserved by the French Bureau of Standards. All other standard masses are ultimately calibrated against the prototype kilogram. A direct measurement of mass of an object is made by an operational procedure. If an analytical balance is used, the standard is regarded as gravitational mass; if an inertia balance is used, the standard is regarded as inertial mass. Both methods yield the same numerial result for the same object.

A specific object, say a person, has two different properties which

must be carefully distinguished. The mass of a person specifies his inertia, that is, resistance of change of motion. Mass is measured in kilograms. The weight of a person specifies the gravitational force which acts on him and is expressed in pounds. A certain person on the surface of the earth might have a mass of 75 kilograms and a weight of 165 pounds. The same person on the surface of the moon would have the same mass, 75 kilograms, but would weigh about 30 pounds.

The standard unit of time is the second, which is ultimately specified by the duration of one of the recurrent motions in nature—the revolution of the earth around the sun. A certain laboratory refers its time measurements on its own standard clock. This clock is calibrated against radio time signals from the Bureau of Standards, which in turn calibrates its master clock from the revolution of the earth as measured by sighting at the fixed stars. For the scientist, time is defined operationally as "the number read from this calibrated clock."

After the three basic units—meter, kilogram, second—are defined, one proceeds to the compound quantities. The simplest of these is velocity. If an object travels 30 meters in 3 seconds, its average velocity is 30 meters divided by 3 seconds, that is, meters/second. The unit of velocity is thus meters per second, abbreviated as m/sec. It may be noted that the process of division is explicitly indicated by the slanting line. All compound units can be thus referred to the basic three units, but in practice one often renames common combinations. For example, the coulomb/second is renamed the ampere.

Length, mass, and time are scalar quantities, that is, they are describable by hyper numbers with one element. Displacement on a surface is a vector quantity and requires a hyper number with two elements, the first to specify the magnitude of the displacement and the second to specify the direction.

The next compound quantity is acceleration, also a vector quantity. Suppose a car accelerates from rest to 30 m/sec. in 10 seconds; the quantitative measure of the acceleration is obtained by dividing the change in velocity by the interval of time required. The result is 3 meters/second each second, usually abbreviated to 3 m/sec^2. Note that the compound unit, as it were, preserves and indicates the process by which the quantity was obtained.

Now that the units of mass and acceleration are defined, we can use Newton's second law (force equals mass multiplied by acceleration) to define a unit of force. The new unit of force, the kilogram meter/second^2 is named the newton. The pound equals about 4.5 newtons.

The quantity of work is defined quantitatively as the product of force applied, time and distance moved in the direction of the force. It is a scalar quantity, and the unit newton meter is renamed the joule.

One can proceed in a similar fashion to build up other compound

units. For example, pressure is newtons/m², density is kilograms/m³, and so on. Fortunately, only a few of the infinite number of unit quantities obtainable in this way are useful in making predictions in physics. The early history of physics concerned itself with finding which of these combinations were useful and which are not. Let us use M for mass and V for velocity. The vector quantity MV was found useful and named momentum. The scalar quantity 1/2 MV^2 was found useful and named kinetic energy. Products such as MV^3 and M^2V occur too seldom to be honoured by special names.

Science is concerned with prediction. When a quantity does not change, prediction is particularly simple. A quantity which remains constant during a given process is said to be conserved. When two steel balls collide, the total momentum of the pair (the vector sum of the two separate momenta) is conserved. This is an example of the law of conservation of linear momentum. In this example the total energy (the scalar sum of the two separate kinetic energies) is not conserved, but in the low-energy collision of atoms energy is conserved.

Conservation laws are indications of symmetry in nature. An object may move along a line or rotate or both. The law of conservation of linear momentum holds when the motion is invariant under spatial translation of the coordinate axes of the observer. The law of conservation of energy holds when the motion is invariant under temporal translation of the coordinate axes of the observer.

The concept of field is one of the most basic ideas of contemporary physics. A field is a region of space where a test object experiences its specific force. The vector quantity field intensity is measured by the force which acts on a unit test object.

For the gravitational field the unit test object could be a small piece of metal having a mass of one kilogram. The space surrounding the earth is a gravitational field. Near the surface of the earth a kilogram mass suspended from a spring balance indicates that the field intensity is 9.8 newtons per kilogram directed toward the centre of the earth. When measurements are made farther from the earth, the field intensity decreases as the inverse square of the distance from the centre of the earth. In principle the field intensity never becomes zero even at enormous distances, but it does become immeasurably small.

The space surrounding a stationary electron or a collection of stationary electrons is an example of an electric field. The space surrounding a magnet is an example of magnetic field. Fields may be mapped by making a scale drawing of the source of the field (that is, the earth, electron, or magnet) and drawing curves such that the tangent at any point gives the direction of the field at that point. A mapping of the field of the earth or the electron would consist of a family of radial lines converging toward the centre of the earth or the electron. The familiar pattern of lines formed by iron filings near a magnet constitutes a mapping of the magnetic field of the magnet.

The concept of potential is closely associated with the concept of field; the two are easiest to understand in their mutual relationship. Field intensity is a vector quantity that describes the behaviour of a unit test object within a region of space by specifying the force which acts at each point of the space. Potential is a scalar quantity that describes the behaviour of a unit test object by specifying the work needed to bring the test particle to each point of the space. The test particle is brought to the point of interest from a great distance where the field force on the particle is negligible. The path followed does not affect the total work done. In the language of mathematics, one says that the particle is brought in from infinity and that the zero of potential is taken at infinity.

Having considered the electric and gravitational field, we must proceed to the magnetic field. The lines of force of a magnetic field can be traced using a small magnetic compass; the north pole of the compass acts as the test object for the field. There is an intimate relation between electric and magnetic fields. The empirical facts were discovered during the nineteenth century by a large number of experimentalists, and put into mathematical form by James Clark-Maxwell (1831-1879). The experimental facts are essentially that (1) a moving electric charge (say an electron) produces a magnetic field and (2) a moving electric charge crossing an already existing magnetic field finds itself pushed sideways. There are four Maxwell differential equations when written in vector form. The first specifies how electric fields arise from electric charges, the second describes how magnetic fields are related to the fact that magnetic poles always occur in pairs—one north and one south pole. The third equation specifies that a changing electric field gives rise to a magnetic field and the fourth describes how a changing magnetic field gives rise to an electric field. The four Maxwell equations consitute three-dimensional models of electromagnetic phenomena. There is also a four-dimensional relativistic model in which there are two tensor equations, and the electric and magnetic fields are regarded as two aspects of one basic entity. The two models, of course, are equivalent.

The Maxwell equations describe that aspect of nature which gives rise to the phenomenon we call light. If a changing electric field is generated by causing electrons to surge back and forth along a wire, then a changing magnetic field also arises and the two change rhythmically together in the same region of space. At low frequencies, say a few hundred cycles per second, the changing electromagnetic field exists only near the wire. However, when the frequency rises to a few million cycles per second or higher, the pulsing electromagnetic field propagates itself away from the wire at a velocity of 300 million meters per second. Thus arises the electromagnetic wave. In such a wave the changing electric field produces a changing magnetic field, and the changing magnetic field produces another changing electric field in a lightning-fast game of leapfrog. Light is an electromagnetic

wave having a frequency between 430 and 750 million cycles per second; the human eye is sensitive to frequencies in this range, and the retinal impulse to the brain is called the sensation of light. The various frequency ranges of electromagnetic radiations have been given different names as they were discovered and investigated historically. The whole range of frequencies is called the electromagnetic spectrum.

The concept of energy, which has proved basic in mechanics and in the field of physics, is also fundamental for thermodynamics. The development of the steam engine near the beginning of the nineteenth century led to a surge of interest in the computation of the mechanical energy (work) available from a given amount of thermal energy (heat). The basic experimental facts are that objects can be classified qualitatively as hot or cold by touching them, and that when a hot object is in contact with a cold object, the two soon reach an equilibrium condition where both feel the same. The invention of the thermometer permitted a quantitative measurement of the property described qualitatively by the adjectives *hot* and *cold*.

An early model of these phenomena postulated the existence of a substance named *caloric*; the temperature of a substance depended directly on its *caloric* content. When a hot object was in contact with a cold object, caloric flowed from the hot object to the cold object until their temperatures were the same. The notion that caloric was a substance was revised when it was found that (1) caloric appeared to have zero mass bacause there was no measurable change in the mass of an object when it was heated and (2) caloric was not conserved, that is, caloric could be created in a body in unlimited amounts by doing frictional work on the body. The conclusion that caloric was not a substance was valid because of reason (2) even though reason (1) is now known to be invalid; a body does increase in mass when it is heated, but the increase is unmeasurably small.

The revised model postulated that the temperature of a body was a measure of the average kinetic energy of the chaotic motion of the particles of the body. For example, the molecules of a block of ice are arranged in a regular pattern. When the ice is as cold as possible (absolute zero temperature) the molecules are essentially motionless at their lattice positions. If the ice is heated, the molecules begin to vibrate chaotically about their lattice positions; the molecules now have an average kinetic energy of chaotic motion, and this average, multiplied by an appropriate constant, is the absolute temperature of the ice. If the heating process is continued, the motion becomes more and more violent until the lattice forces can no longer hold the molecules near the lattice positions and the arrangement of molecules becomes disordered; the ice has melted and changed from the solid to the liquid phase. This melting occurs when the temperature has reached +32°F. If the heating is continued, the chaotic motion of the disordered molecules increases, but the molecules are still held fairly close together. At +212°F the chaotic motion is so violent that

the intermolecular forces can no longer hold the molecules fairly close together, and the molecules start flying apart; the water boils and changes from the liquid to gaseous phase. Further heating increases the temperature of the gas; eventually the molecules are dissociated, and then the atoms, and finally at a temperature of millions of degrees the nuclei themselves are knocked apart.

The intuitive meaning of the word *heat*, used as a verb, is clear enough; its meaning as a noun is very subtle, and is best left to the experts. The difficulty lies in the intuitive notion that if you put 3 joules of heat into a body, then that body ought to contain 3 more joules of heat than it did before. It is true that, if no external work has been done, the body contains 3 more joules of energy than it did before, but that energy is not necessarily in the form of heat—some of it may be in the form of internal potential energy. For example, you can supply 335,000 joules of heat to a kilogram of ice at $+32^0$F and the temperature does not increase at all; the heat has been converted to internal potential energy. The difficulty with heat as a noun is that it is not conserved. For the record, then, heat is that form of energy in transit which flows from one body to another because of a difference in temperature. The word is not properly used except when the energy is flowing; there is no uniquely definable quantity which can be called the "heat content" of a body. Heat can flow by conduction, as along a metal rod; by convection, as in the air currents above a hot object; or by radiation, as in an electromagnetic wave.

We must now contrast the two concepts *heat* and *temperature*. Temperarure is measured in degrees with a thermometer. Heat is measured in joules (or calories) with calorimeter. The temperature of an object is an intensive property; it does not depend on how much of the object there is. Heat is an extensive property; it takes twice as much heat to change the temperature of two gallons of water by one degree as it does to change one gallon of water by the same amount. Temperature is a measure of the average kinetic energy of chaotic motion of the particles of a body. Heat is a measure of flow energy due to difference in temperature.

In order to understand the laws of thermodynamics we must define the concept of entropy. Entropy is a quantity which measures the disorder of the particles of a body; it is an extensive property. In contradiction to "heat content," which is not unique, the "entropy content" of a body is a unique number. Entropy depends on the temperature of a body, and increases as the temperature increases. Entropy is measured in the unit *calorie/kilogram/degree*. It may be measured experimentally by long series of measurements with a calorimeter, or, if enough is known about the structure of a substance, it may be computed. It is postulated that a pure crystalline substance at absolute zero has entropy zero, and this postulate has been called the *third law of thermodynamics*. Most practical problems are concerned with change in entropy; such changes do not depend on any particular

choice for zero of the entropy scale.

There are two general laws in thermodynamics:

(1) Within a thermodynamic system (say a steam engine) the heat supplied equals the work done plus the change in internal energy.

(2) The maximum work which can be obtained from a cyclic thermodynamic process equals the change in temperature multiplied by the change in entropy.

The first law is seen to be a statement of conservation of energy regarding work and heat as forms of energy.

The second law tells us that no work can be done without both a change in temperature and a change in entropy of the "working fluid" of the engine. There are many other equivalent statements of the second law.

The two laws just quoted are the historic expressions of the basic laws of thermodynamics. The same ganeral information can be expressed in a different way which shows more clearly the tendency of thermodynamic processes. These may be called the "A" and "B" laws of thermodynamics:

(A) Work may be changed to heat at 100 per cent efficiency.

(B) Heat may be converted to work, but at efficiencies that are always less than 100 per cent and usually less than 50 per cent.

If these laws apply uniformly throughout the universe, a progressive change of work into heat without a balancing change of heat into work is indicated. Apparently the universe is "running down," and in the remote future it will consist of a disordered cold soup of matter dispersed throughout space at a uniform temperature of a few degrees above absolute zero. Another way of expressing the same prediction is, "The entropy of the universe tends always to increase." During the growth of living organisms, entropy decreases within the organism. All indications are that the surrounding environment increases in entropy more than enough to balance the local decrease. Perhaps in some remote part of time or space there is a fountain of negentropy that some Ponce de Leon of the future may seek or even find.

We have now defined a scientific and mathematical vocabulary sufficient for a brief discussion of *quantum* mechanics, the most sophisticated model yet developed of physical phenomena. Quantum mechanics includes the successful parts of many previous models; Planck's quantisation of radiant energy, Bohr's quantisation of angular momentum and energy states, Schrodinger's wave mechanics, Heisenberg's matrix mechanics, Dirac's treatment of electron spin, and contributions from many other physicists, chemists, and methematicians. Quantum mechanics is assumed to apply to all physical measurements, and it includes Newtonian mechanics as a special case. It also includes

the restricted theory of relativity, but its relationship to general relativity is not yet clear. In quantum mechanics the laws of nature appear as restrictions upon the value of the commutator rather than as the solutions of differential equations as in previous models.

The following statement of the postulates of quantum mechanics is rewarded from a formulation by Henry Margenau.*

(1) To every observable quantity there corresponds an operator;

(2) A measurement of an observable quantity can yield only certain specific numbers, the eigenvalues of its operator;

(3) To every state of a system there corresponds a state-function;

(4) The average of a series of measurements of an observable quantity from a system in a specific state may be computed from an expression in which the corresponding operator acts upon the corresponding state-function;

(5) The rate of change of a state-function with time may be computed from the action of the energy operator upon that state-function.

The second postulate seems very respective. For example, when measuring the linear momentum of a free particle, one would expect to encounter any number—positive, negative, or zero. This expectation is compatible with the second postulate because the operator for linear momentum of a free particle has an infinite set of eigenvalues, namely, all real numbers, positive, negative, or zero. On the other hand, the operator corresponding to the angular momentum of the electron in the hydrogen atom has for eigenvalues only certain specific number—those which were listed *ad hoc* in the postulates for the Bohr model of the hydrogen atom.

From these five postulates can be derived the Schrodinger equation, which constitutes the Schrodinger model of the atom. The Schrodinger model predicts with great accuracy the measurable effects which depend on the behaviour of the electrons surrounding the atomic nucleus. Quantum mechanics is currently being used to correlate and predict measurements which depend on the behaviour of parcticles within the nucleus. The predictions are accurate enough so that theorists expect that the quantum-mechanical model will probably be valid for the nuclear domain. It is not yet clear what additions or modifications will be needed to permit highly accurate predictions.

When it was found in 1901 that light (ordinarily considered a wave) also had particle-like characteristics, and when, in 1927, the electron (ordinarily considered a particle) was also found to have wave-like characteristics, these facts seemed paradoxical. This reaction was naive because one must not expect the "common sense" of the macroscopic

*H. Margenau, *The Nature of Physical Reality* (New York: McGraw-Hill Book Company, Inc., 1950).

world to persist in the microworld. It is misleading to refer to the "dualistic" nature of light merely because an entity has different aspects depending on the mode of observation. The shadow of a cylinder can be observed as a disk or as oblong, but the cylinder remains a single entity. However, one chooses to describe the complementary aspects of fundamental particles, this complementarity is built into the very basis of the quantum-mechanical model. For example, the mathematical expression for the state-function of a beam of photons may be reduced by one path of thought to a recognisable description of a wave, or it may be reduced by another path to a description of a particle. These two *isomorphic* models are inherent in the original state-function, which is not itself committed to either aspect alone.

The Heisenberg indeterminacy principle states that momentum and position cannot be simultaneously measured, with arbitrary accuracy. Momentum and position are said to make up a "complementary pair" of quantities. Another such pair is time and energy. In 1928 Niels Bohr formulated the *principle of complementarity*, which states that there exist pairs of quantities in nature so related that an experiment designed to measure one of the quantities will interfere with the system in such a way that the conjugate quantity cannot be measured accurately. The quantitative aspects of this principle are expressed in the principle of indeterminacy. Later Bohr extended complementarity in a qualitative way to include philosophical questions, and suggested that free will and determinism in human behaviour might be conjugate points of view such that a commitment to one of the pair would autc matically eliminate the other from consideration.

Argument

All measurements of the physical world can be expressed in terms of length, mass, and time, each of these is measured by specified operations using an arbitrarily chosen standard, and the result is a single number, a scalar quantity. Compound quantities such as density, velocity, acceleration, etc., are ultimately defined and measured by measurements of length, mass, and time, and it is found that the results may be described by hypernumbers of various sorts.

Any compound quantity whatever may be defined, but only those quantities most useful for prediction have been retained for general use. Compound quantities which remain constant with time are especially useful because they simplify prediction. Such quantities are said to be conserved, and are described by *conservation laws;* examples are energy, linear momentum, angular momentum. Conservation laws are indications of symmetry in nature; a quantity is conserved when it is invariant under tanslation or rotation of axes or other aspects of axis systems which are subject to arbitrary choice by the observer.

A field is a portion of space where a test object experiences its specific force. *Field indensity* is a vector quantity defined at each point of the field. Three common examples of fields are the gravitational, the

electric, and the magnetic field. The motion of a body in a field may be predicted from the laws of mechanics when the field intensity at each point and the initial conditions are known. The potential is a scalar quantity defined at each point of a field. The field intensity at each point may be computed from the values of the potential near the point and conversely.

Heat is a form of energy. If no energy enters or leaves a region, then the total energy of that region will remain constant (be conserved), but, heat being only one form of energy, may not be conserved. Thermodynamics deals with the natural laws which describe the changes of form of energy within a particular region. Thermodynamics uses only macroscopic quantities (temperature, pressure, volume and the like), and its relations are usually independent of molecular, atomic, and nuclear structure.

Quantum mechanics is the most general model of physical behaviour yet formulated. It includes Newtonian mechanics and restricted relativity, but its relation to general relativity is not yet clear. Quantum mechanics predicts very accurately the behaviour of all objects outside the atomic nucleus. It is currently being applied with considerable success in predicting the behaviour of objects inside the nucleus, but the task is not complete.

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